HKS experiment status (E01-011 Preparation)

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Jlab Hall C Meeting
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Current issues of hypernuclear physics

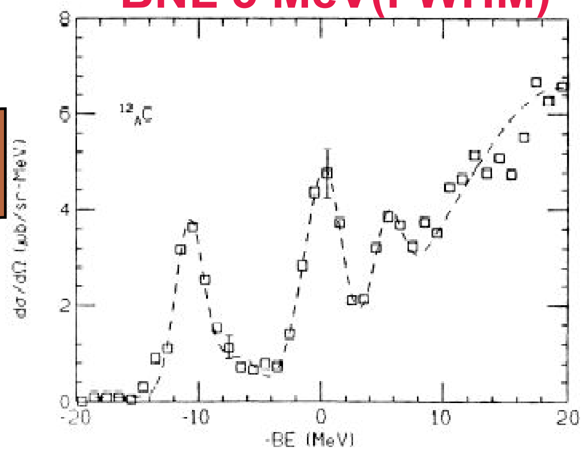
- New degree of freedom
  - probes deeply bound states
  - baryon structure in nuclear medium
- New nuclear structure with strangeness
  - nucleus with a new quantum number
  - electromagnetic properties
- Hyperon-nucleon, hyperon-hyperon interaction
  - hypernuclear structure vs. hyperon scattering
  - S=-2 system and beyond

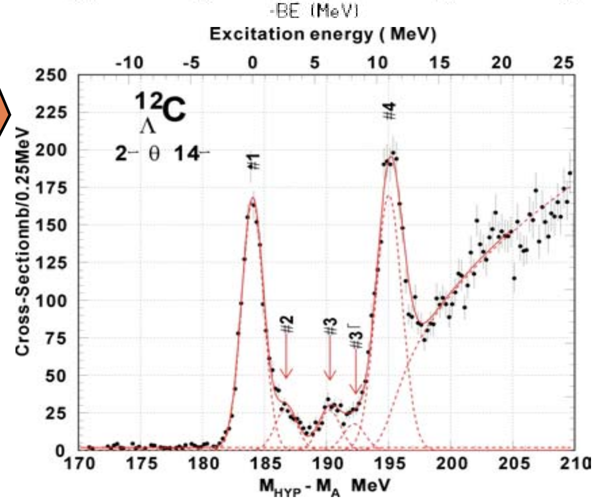
high quality spectroscopy plays a significant role

--- high resolution & high statistics ---

$^{12}C(\pi^+,K^+)\ ^{12}{}_{\Lambda}C$ spectra by the SKS spectrometer at KEK 12 GeV PS

BNL 3 MeV(FWHM)



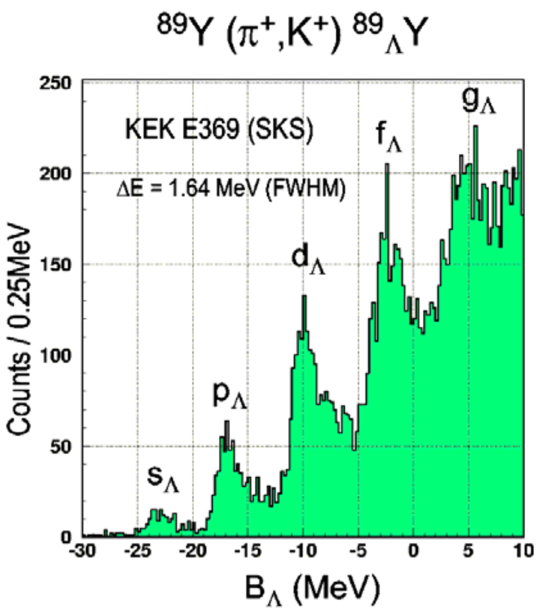


KEK336 2 MeV(FWHM)

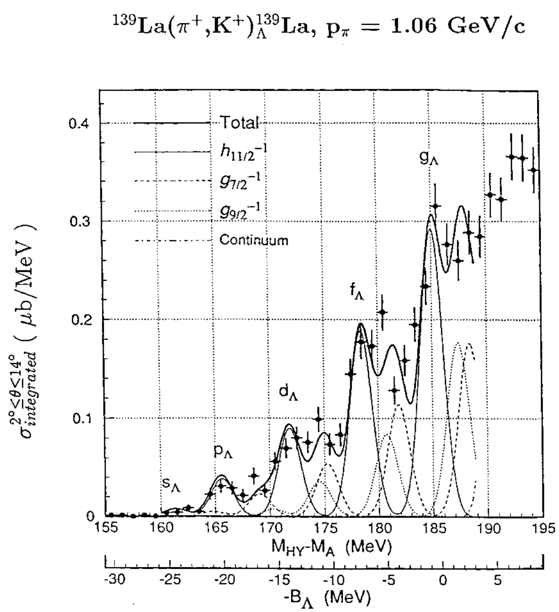
KEK E369 1.45 MeV(FWHM)

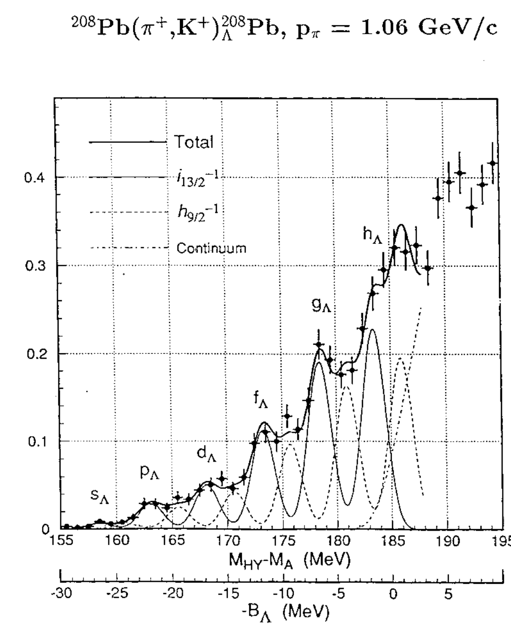
Hypernuclear spectroscopy established

Λ single particle potential



Hotchi et al., PRC 64 (2001) 044302





KEK E140a *Hasegawa et. al., PRC 53 (1996)1210*

Textbook example of Single-particle orbits in nucleus

Λ Single particle states

-> Λ-nuclear potential

depth = -30 MeV -> $V_{\Lambda N} < V_{NN}$

The (e,e'K^+) reaction for hypernuclear spectroscopy

- Proton to Λ – Neutron rich Λ hypernclei
- Large angular momentum transfer
- Spin-flip amplitude

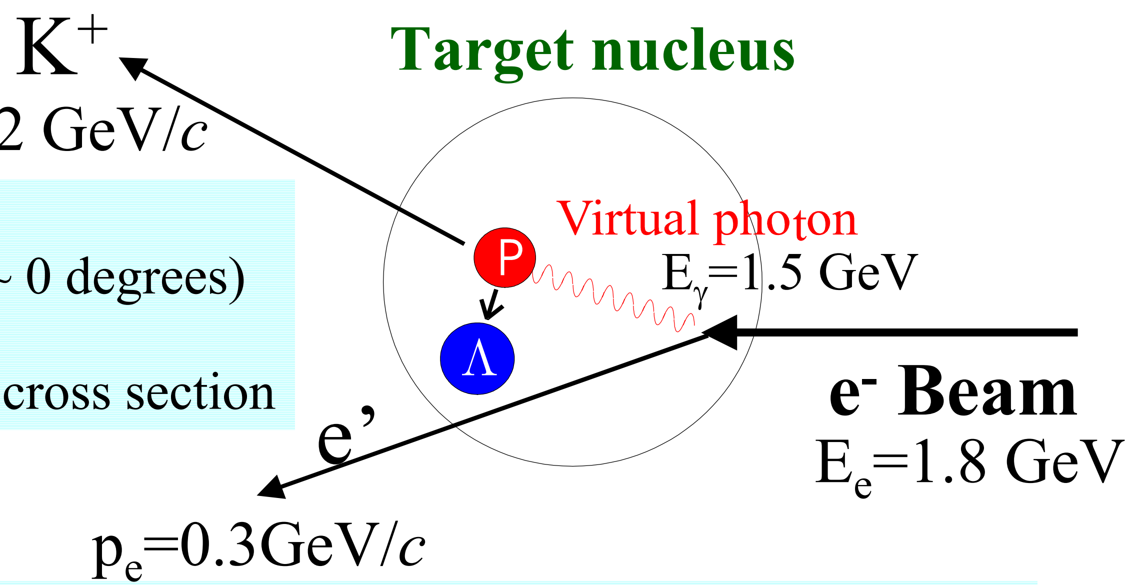
& **Higher energy resolution**

Λ Hyperon production reactions for spectroscopy

$\Delta Z = 0$ neutron to Λ	$\Delta Z = -1$ proton to Λ	comment
(π^+,K^+)	(π^-,K^0)	stretched, high-spin large momentum transfer
In-flight (K^-,π^-)	in-flight (K^-,π^0)	substitutional
stopped (K^-,π^-)	stopped (K^-,π^0)	large momentum transfer
(e,e'K^0) (γ,K^0)	**(e,e'K^+)** (γ,K^+)	spin-flip & large momentum transfer

New generation hypernuclear spectroscopy

Kinematics of the (e,e'K$^+$) spectroscopy



K^+ arm
At very forward angle (~ 0 degrees)
Maximum
hypernuclear production cross section

e' arm
At extremely forward angles
Advantage : Large virtual photon flux
Disadvantage : Huge backgrounds from Bremsstrahlung

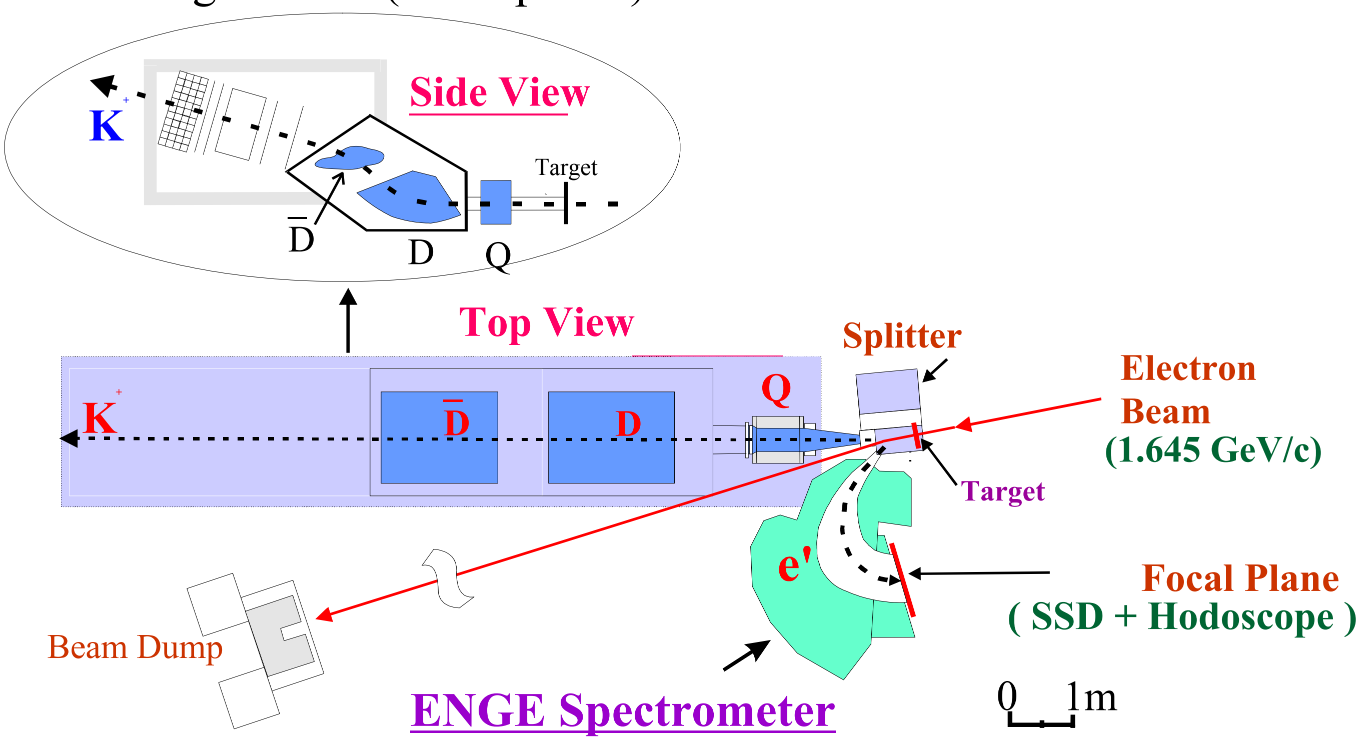
HNSS

SOS Spectrometer

Resolution 5 x 10^{-4}

Solid angle 6 msr(with splitter)

Jlab Hall C HNSS



Resolution 2x10^{-4}

$^{12}C(e,eK^+)^{12}{}_{\Lambda}B$ (E89-009)

Resolution

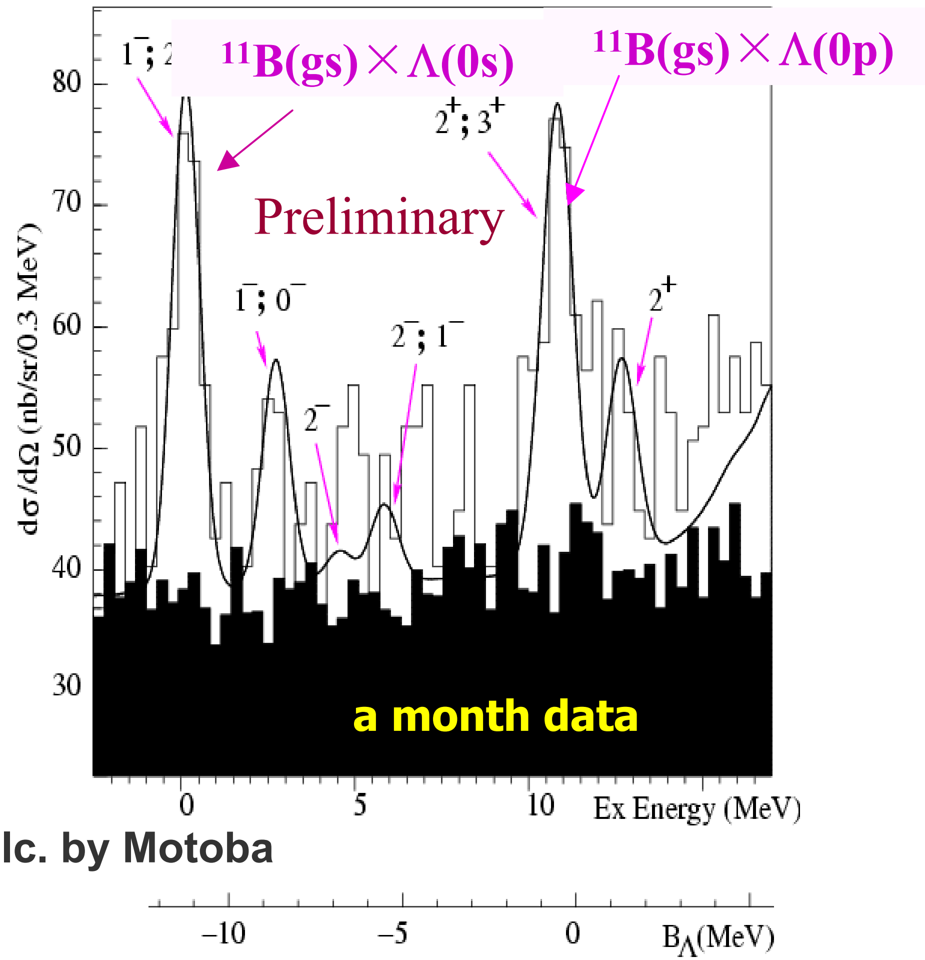
≧1.5 MeV FWHM

by (π^+,K^+)

0.9 MeV FWHM

by $(e,e'K^+)$

A month data taking



calc. by Motoba

Jlab E01-011 experiment

Explore hadronic many-body systems with strangeness through the reaction spectroscopy by the $(e,e'K^+)$ reaction

Immediate goals

- $^{12}C(e,eK^+)^{12}{}_{\Lambda}B$
  - demonstrate the mass resolution & hypernuclear yield.
  - core excited states and splitting of the p_{Λ}-state of $^{12}{}_{\Lambda}B$….
  - Mirror symmetric Λ hypernuclei $^{12}{}_{\Lambda}C$ vs. $^{12}{}_{\Lambda}B$
- $^{28}Si(e,e'K^+)^{28}{}_{\Lambda}Al$
  - Prove the $(e,e'K^+)$ spectroscopy is possible for the medium-heavy target possible.
  - precision $^{28}{}_{\Lambda}Al$ hypernuclear structure and *ls* splitting of p-state….

High-resolution	3-400 keV
High yield rates	> a few 100/day for $^{12}{}_{\Lambda}B$ ground state
	(comparable to the (π^+,K^+) spectroscopy)

Key experimental issues of E01-011

- Electron arm (Learned from E89-009)
  - Tilt method for the scattered electron arm
    - Suppress Brems electrons
    - Need higher order terms of the transfer matrix
- Kaon arm
  - High Resolution Kaon Spectrometer (HKS)
    - High resolution & Large solid angle
    - Good particle ID both in the trigger and analysis

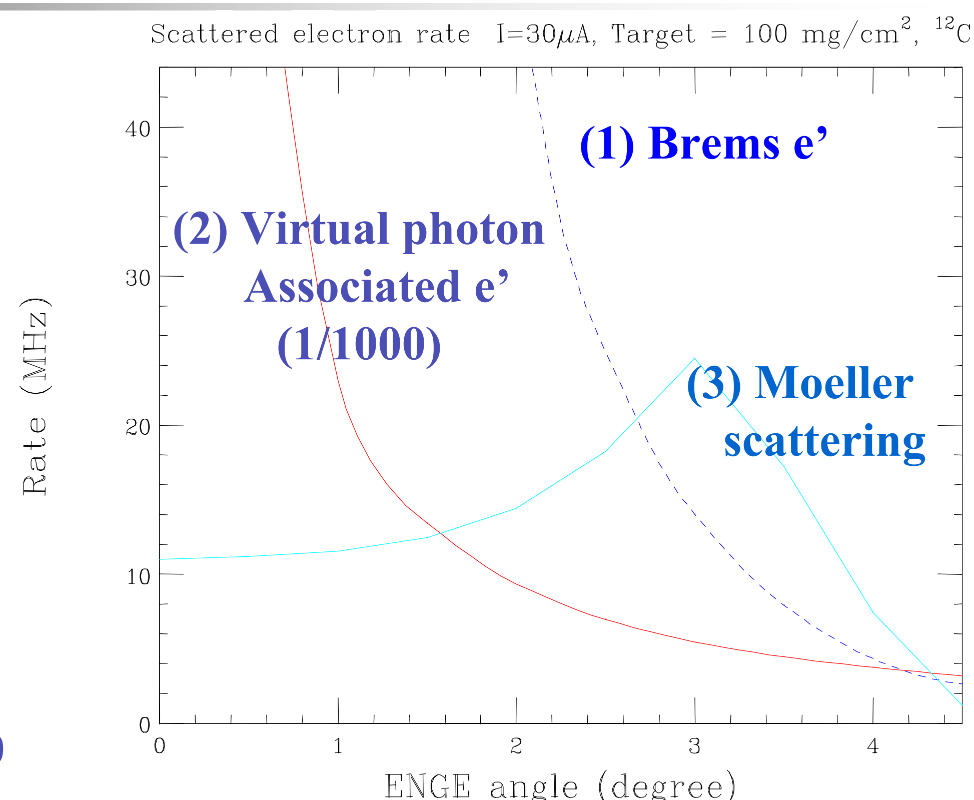
Tilt Method

Scattered electrons (0.2 to 0.4 GeV/c)
(1)from bremsstrahlung
(2)associate with virtual photons
(3) from Møller scattering

Tilt e-arm by 4.5 deg. vertically with respect to splitter & K-arm

Singles rate of e-arm
100 MHz → 3 MHz
with
5× Target thickness
50× Beam intensity

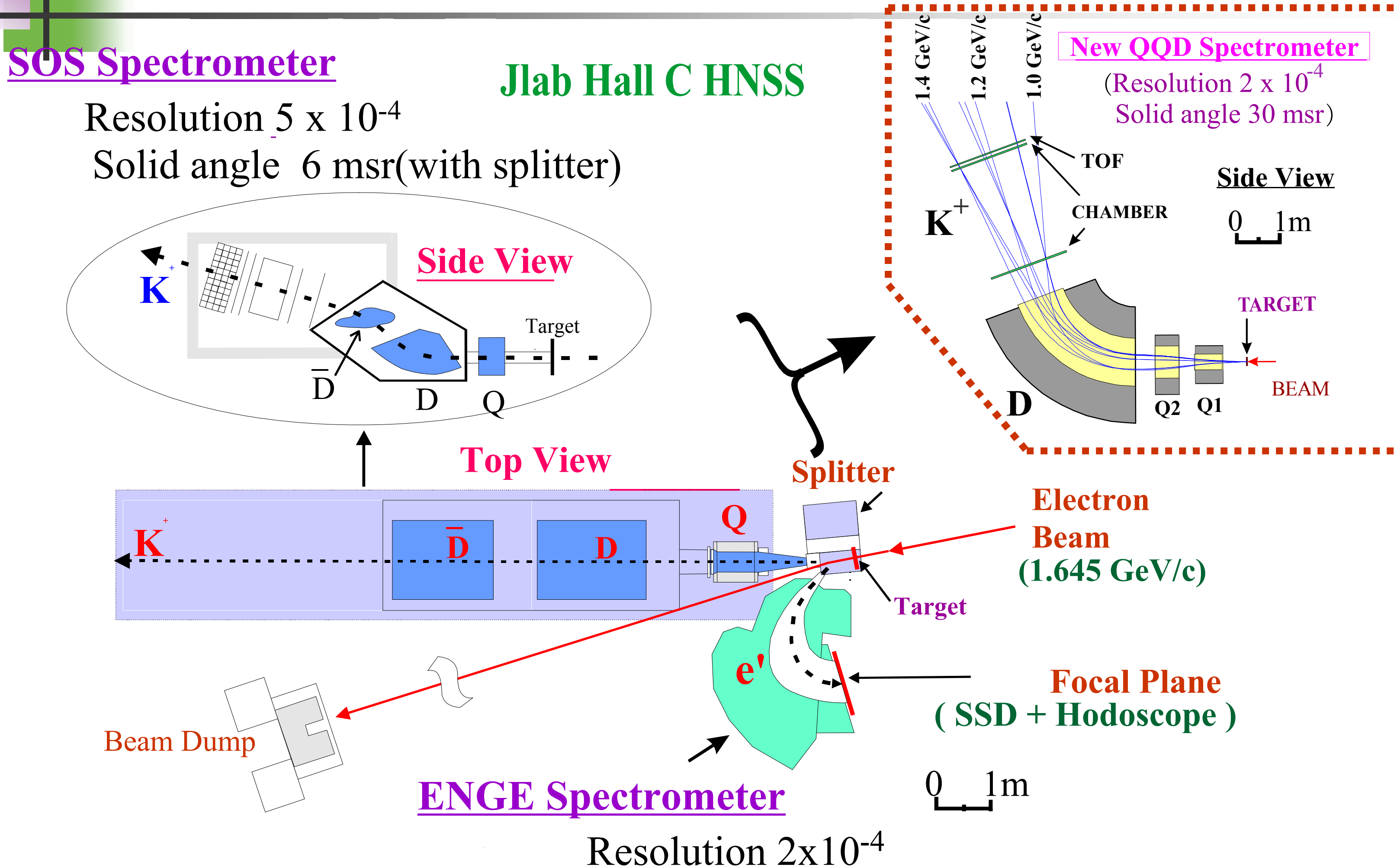
Compared to E89-009



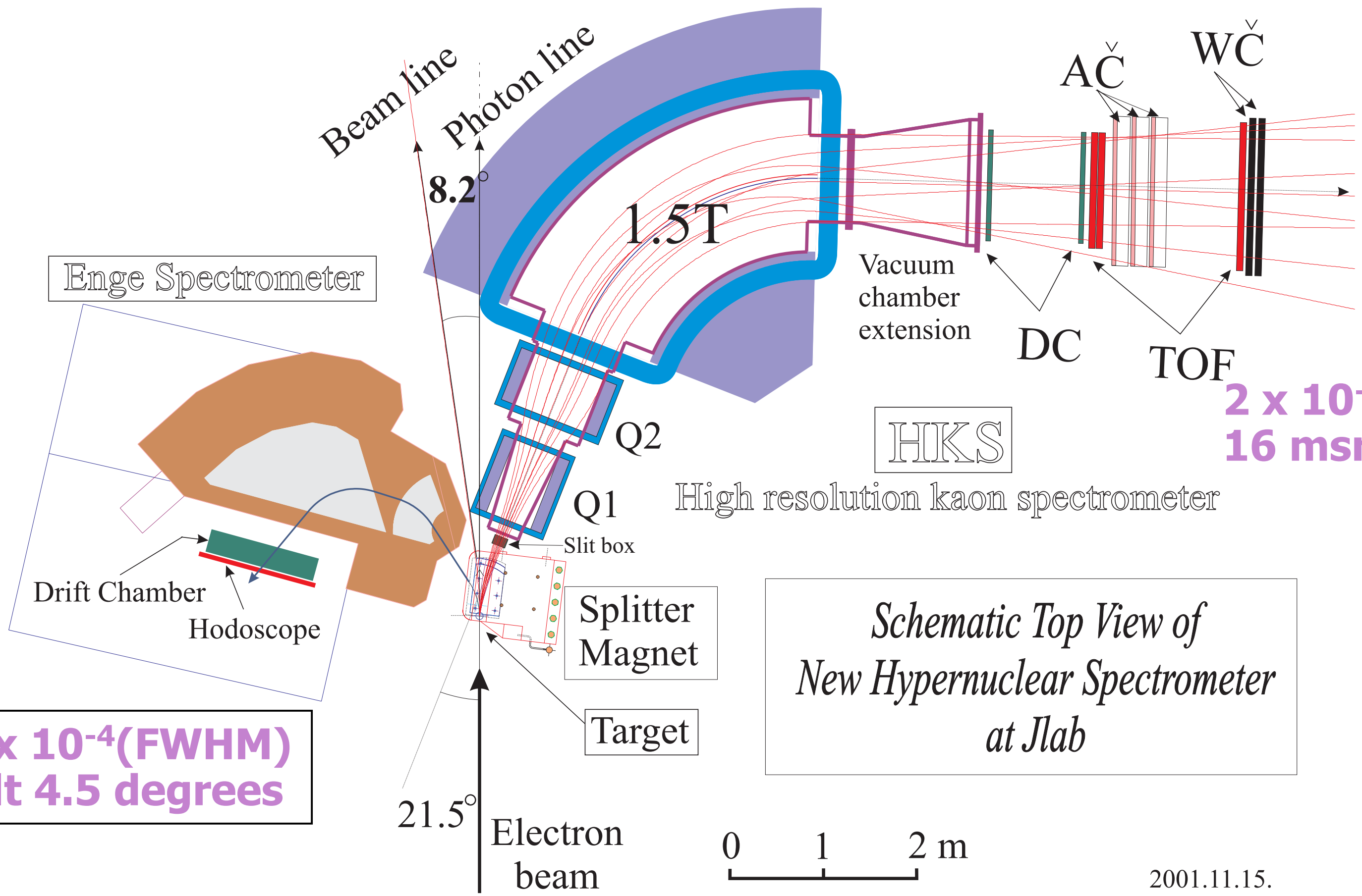
Much better Yield and S/A

Medium-heavy hypernuclei can be studied

HNSS & HKS overview



Layout of the E01-011 setup



2 x 10^{-4}(FWHM)
16 msr with splitter

4 x 10^{-4}(FWHM)
Tilt 4.5 degrees

Expected singles rates

$I_e = 30\ \mu A$, 100 mg/cm^2

Target	HKS				ENGE	
	e^+ (kHz)	π^+ (kHz)	K^+ (kHz)	p (kHz)	e^- (MHz)	π^- (kHz)
^{12}C	-	800	0.34	280	2.6	2.8
^{28}Si	-	800	0.29	240	5.1	2.8
^{51}V	-	770	0.26	230	6.9	3.0
E89-009 ^{12}C	100	1.4	<1Hz	0.14	200	-
	SOS				ENGE	

Measured values at E89-009 $I_e = 0.47\ \mu A$, 22 mg/cm^2

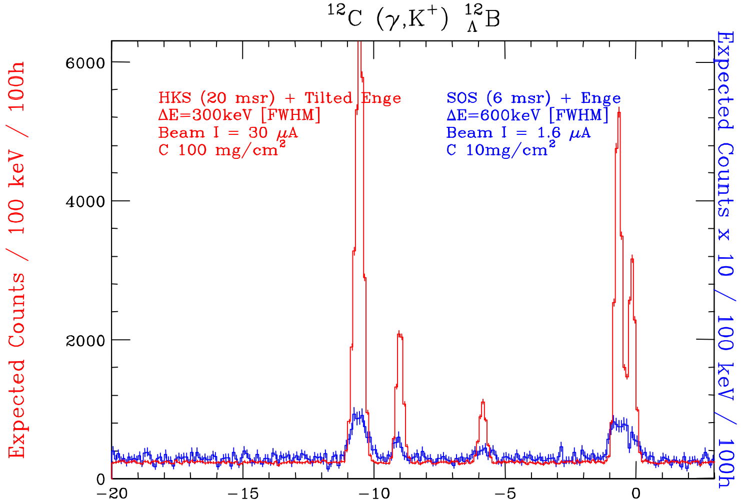
High rejection efficiencies against pions and protons required

Expected energy resolution

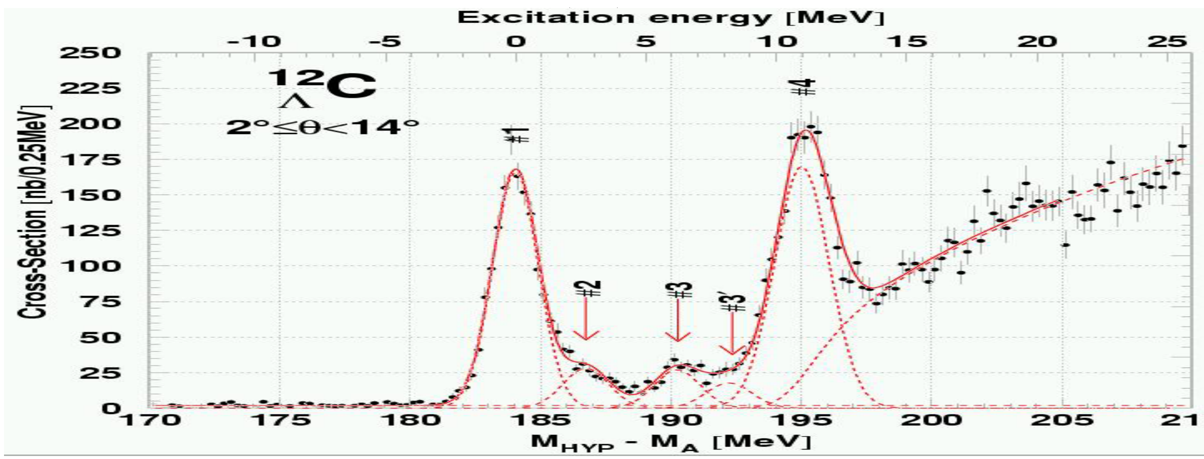
Item	Contribution to the resolution(keV, FWHM)			
Target	C	Si	V	Y
HKS momentum(2×10^{-4})	216			
Beam momentum($<1\times10^{-4}$)	< 180			
Enge momentum(5×10^{-4})	150			
K^+ angle($\Delta\theta=3$mr)	152	64	36	20
Target thickness (100mg/cm^2)	< 180	< 171	< 148	< 138
Overall	< 400	< 370	< 350	< 350

Expected $^{12}{}_{\Lambda}B$ Spectrum

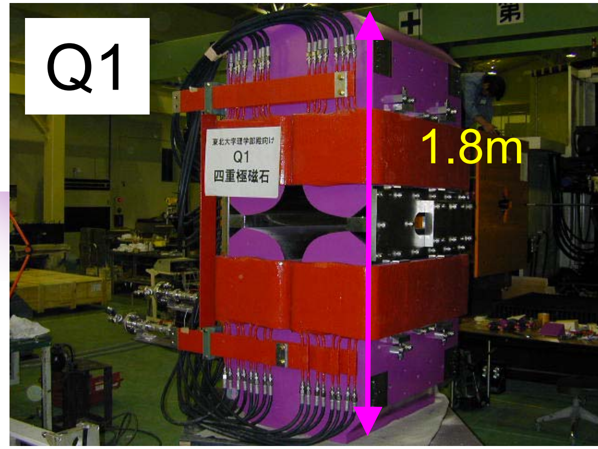
- JLAB E01-011
  [Expected]
- JLAB E89-009
  [Simulated]×10

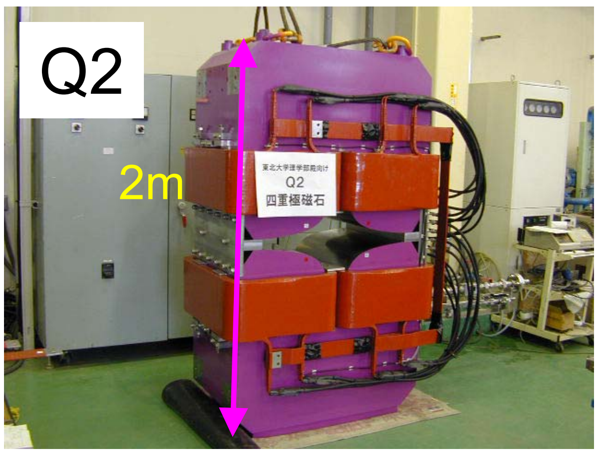


- KEK-PS E336
  SKS (π^+,K^+) reaction
  [Measured]

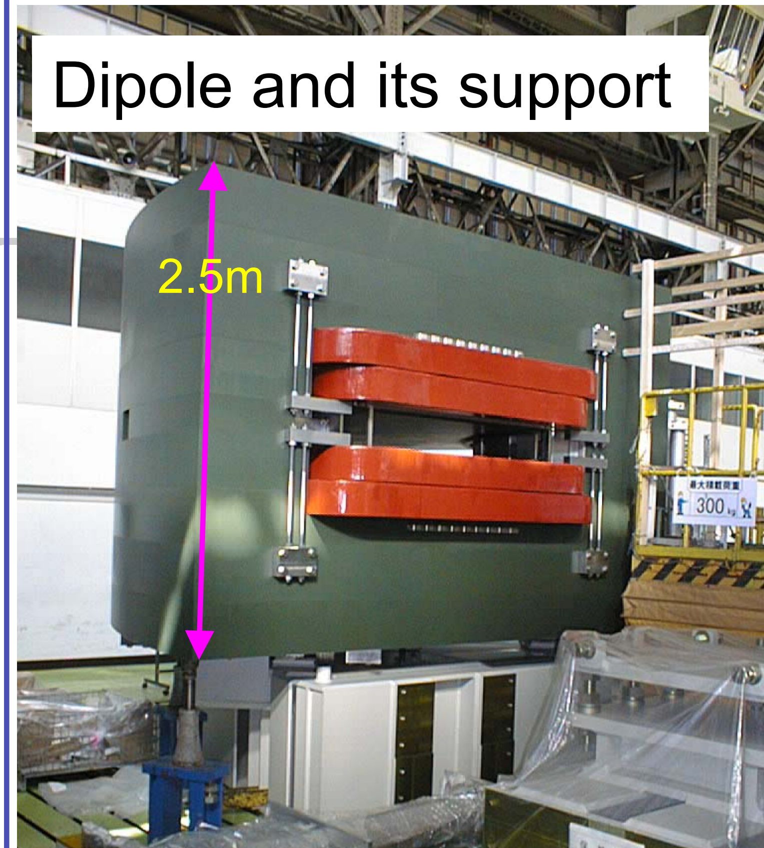


Magnets of the HKS @ Mitsubishi electric corp.





Q1:	
Bore radius	12 cm
Length	84 cm
Field	6.6 T/m
Weight	8.2 ton
Q2:	
Bore radius	14.5 cm
Length	60 cm
Field	4.2T/m
Weight	10.5 ton
Dipole:	
Gap	20 cm
Radius	263 cm
Bending angle	70 deg
Field	1.53 T
Weight	210 ton



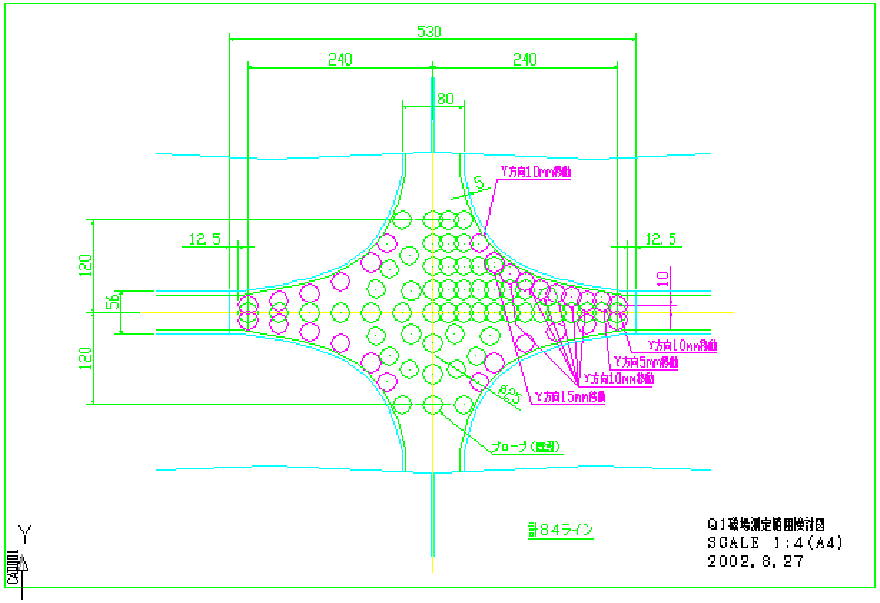
Precision field mapping is underway

Accuracy:	Position	200 μm
	Angle	1 mrad
	Field	0.01%
Mesh size:	2 or 4 cm	
Total # of points	3×10^5	

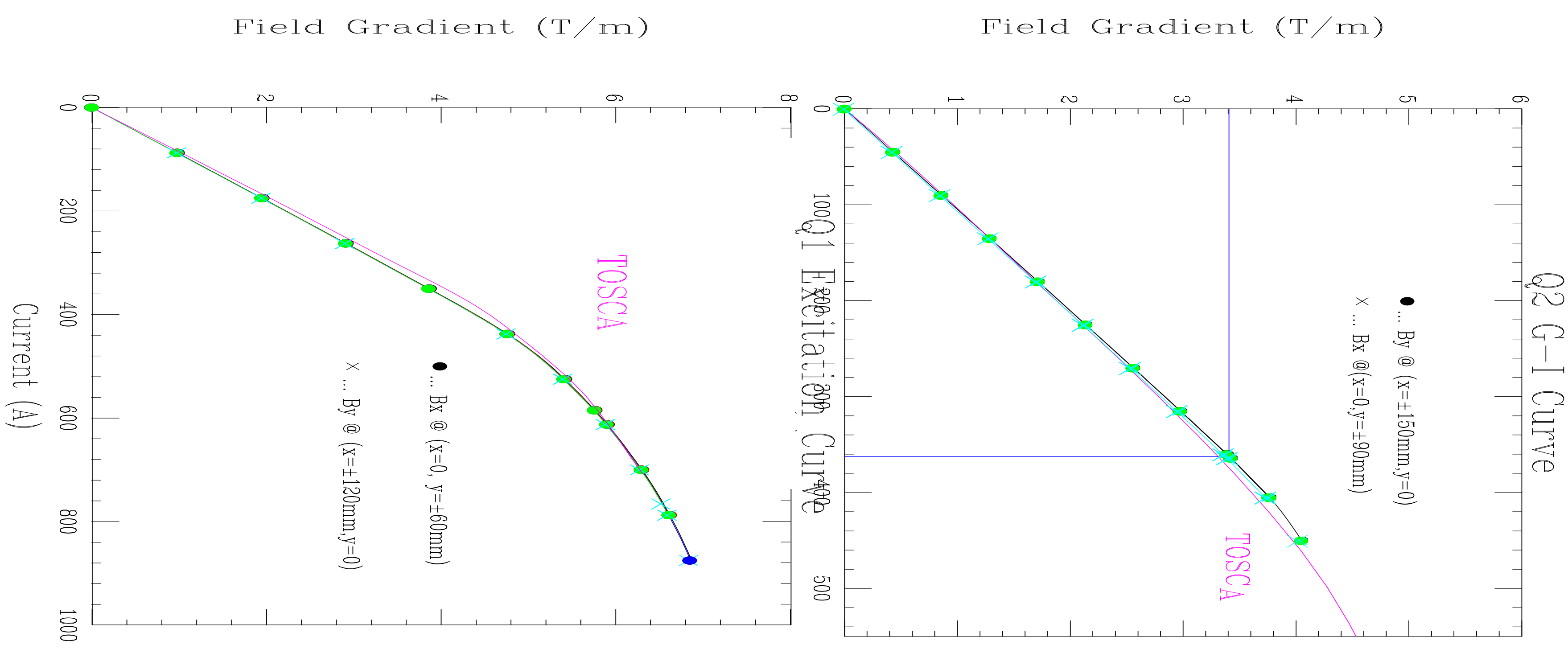
$\delta p/p$
2×10^{-4} (FWHM)
In total

Q1, Q2 field map

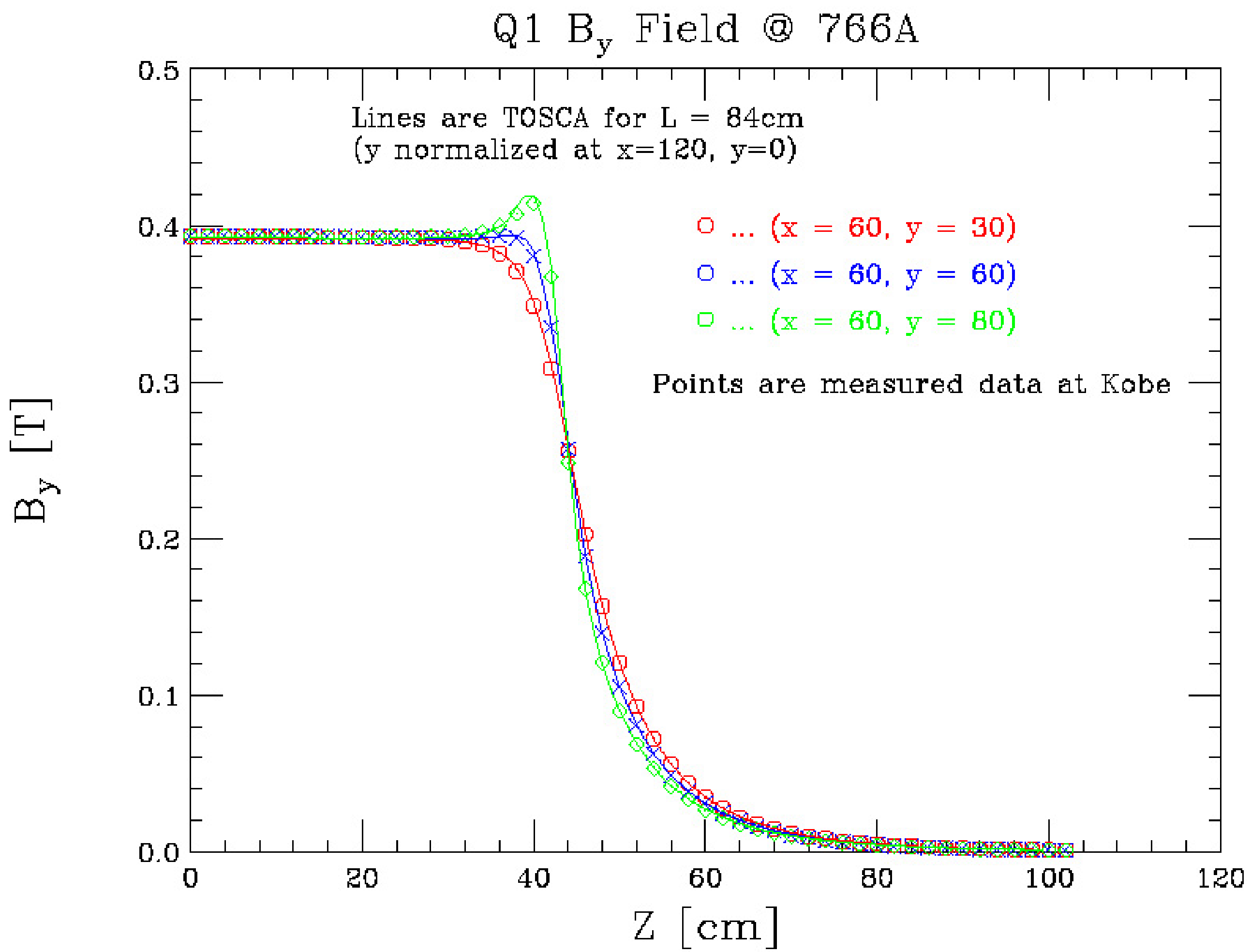
- Use Mitsubishi's 1-direction hall probe
- G-I measurement (Q1 0-875A, Q2 0-450A)
- Measure Bx and By
- 84 lines for Q1
- 92 lines for Q2



Excitation curve for Q1 & Q2

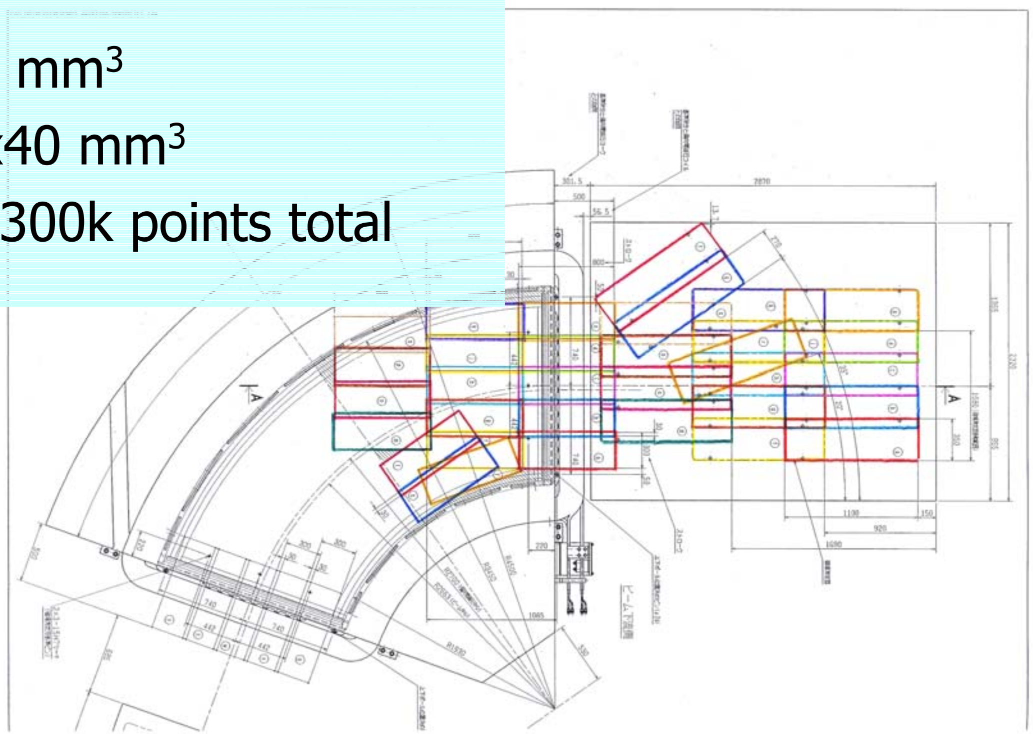


TOSCA calculation vs Q1 map



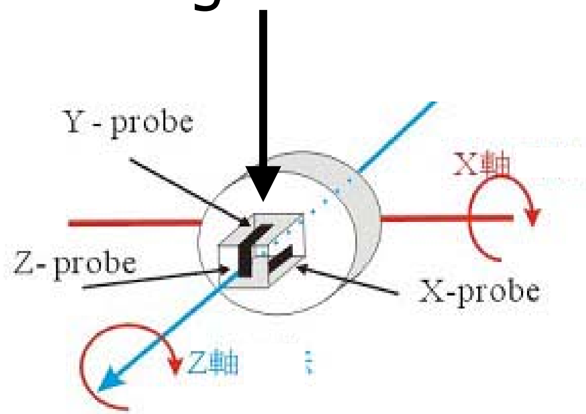
Dipole Field Mapping

- 1 span = 300x800x200 mm^3
- Downstream 19 spans
- Upstream 5 spans
- Fine mesh = 20x20x20 mm^3
- Coarse mesh = 40x40x40 mm^3
- For 5 current settings, 300k points total

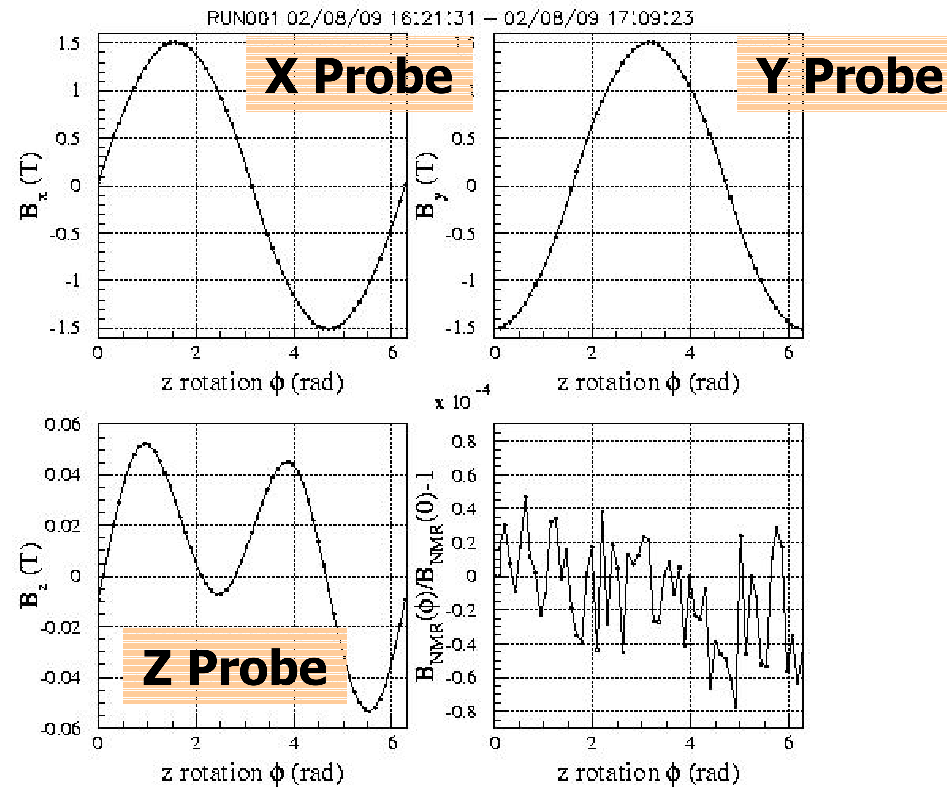


Planer Hall Effect

Mag. Field



Preliminary Analysis of the Hall Planer Effect
Measured at KEK with 8D320 Magnet (8 – 10/Aug/2002)
Magnetic Field B = 1.5 T

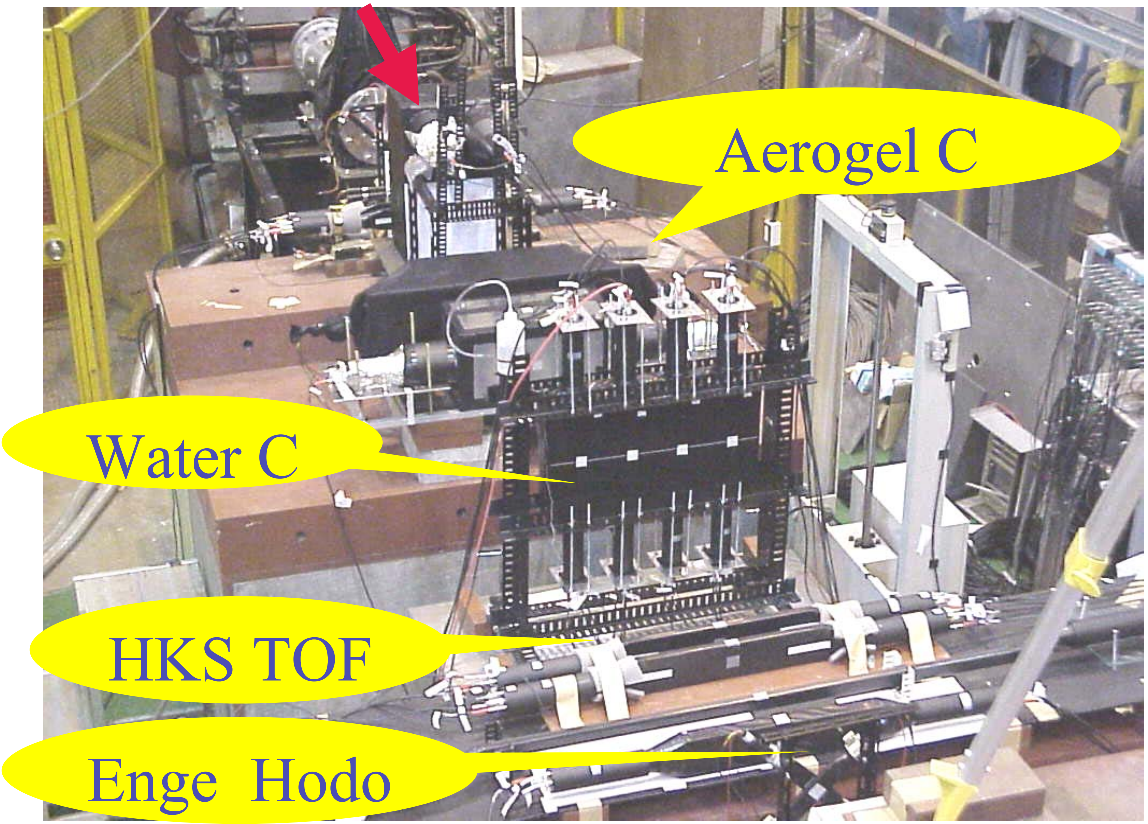


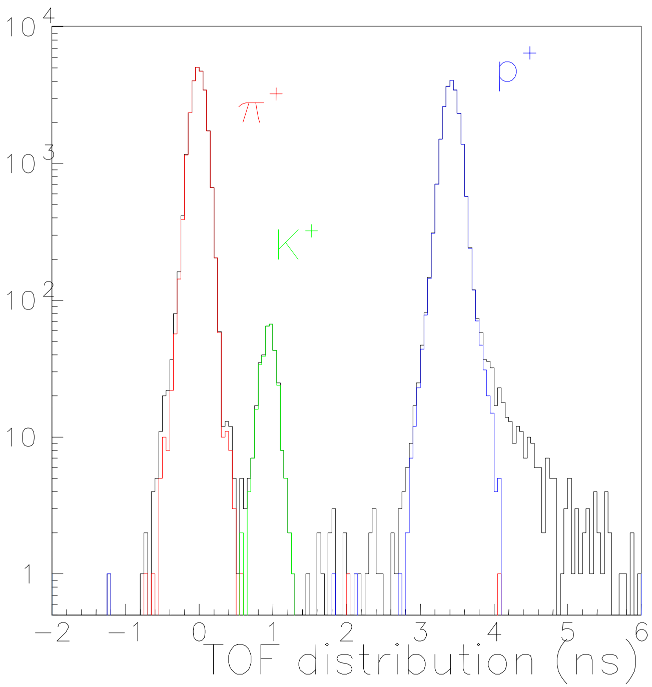
E01-011 Detector List

HKS DC	Hampton	1st one assembled
HKS TOF	Tohoku	*Tested at KEK*
Aerogel C	FIU	1st box fabricated Prototype test at KEK
Water C	Tohoku	Prototype test at KEK
Enge HDC	Tohoku	*Tested at Tohoku LNS*
Enge Hodo	Tohoku	*Tested at KEK*

KEK Test Experiments

π,K,p unseparated beam at 1.05-1.35 GeV/c





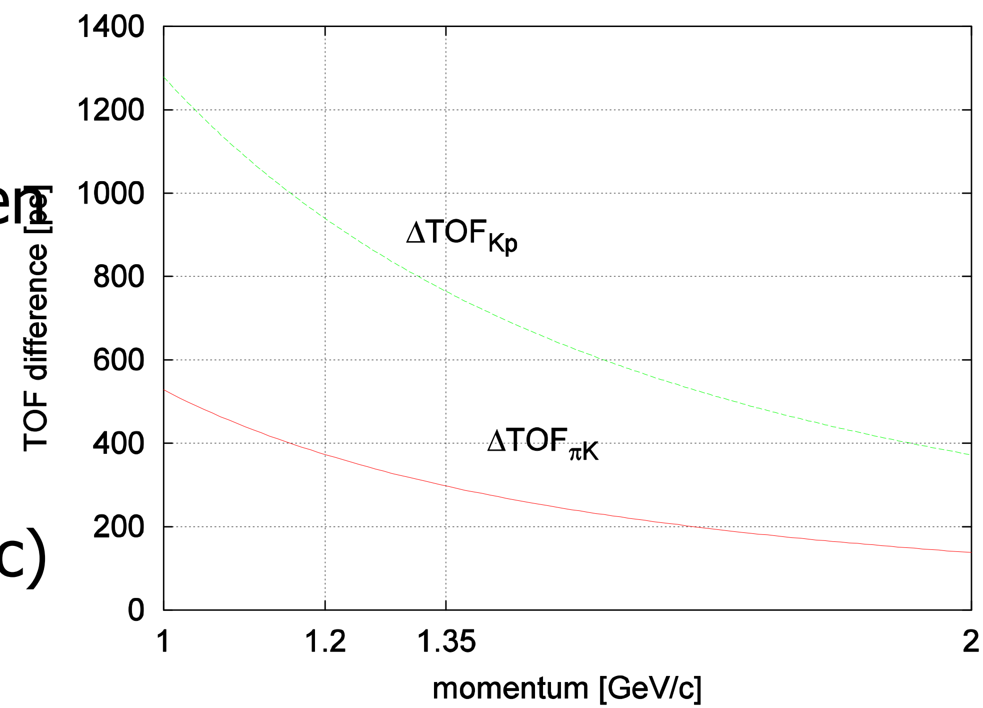
Required performance for timing counter

- Distance between two wall L=1.5m
- 4 σ separation between K^+ and π^+

→ ΔTOF=300ps (@1.35GeV/c)

HKS TOF resolution

75 ps (rms) required



HKS TOF Counter

Scinti. : Bicron BC408

PMT : Hamamatsu H1949

HTOF 1X

$30^{H}\text{cm} \times 7.5^{W}\text{cm} \times 2^{T}\text{cm}$

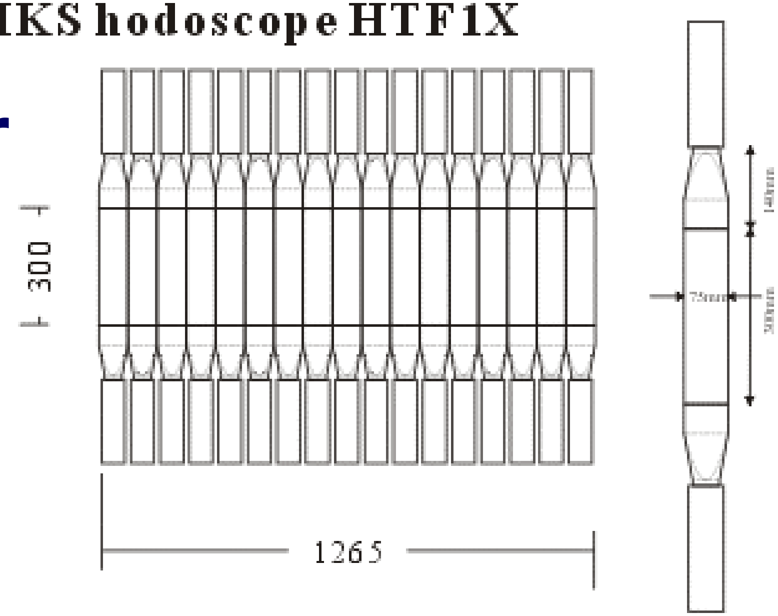
HTOF 2X

$35^{H}\text{cm} \times 9.5^{W}\text{cm} \times 2^{T}\text{cm}$

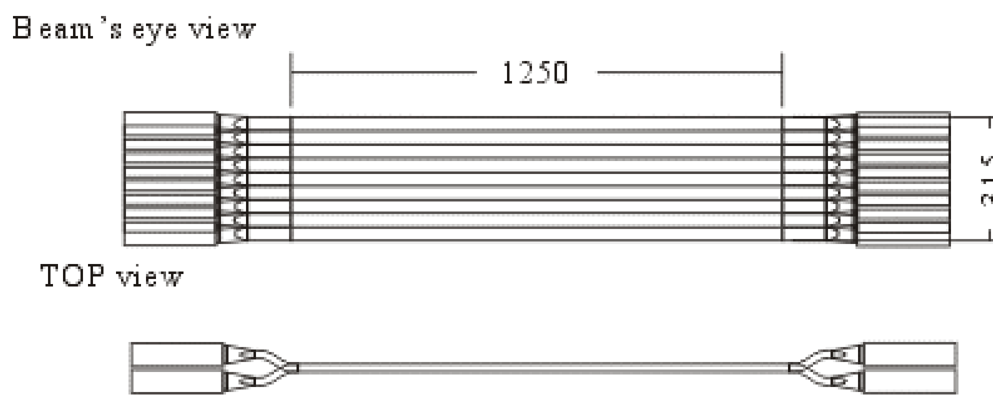
HTOF 1Y

$3.5^{H}\text{cm} \times 125^{W}\text{cm} \times 2^{T}\text{cm}$

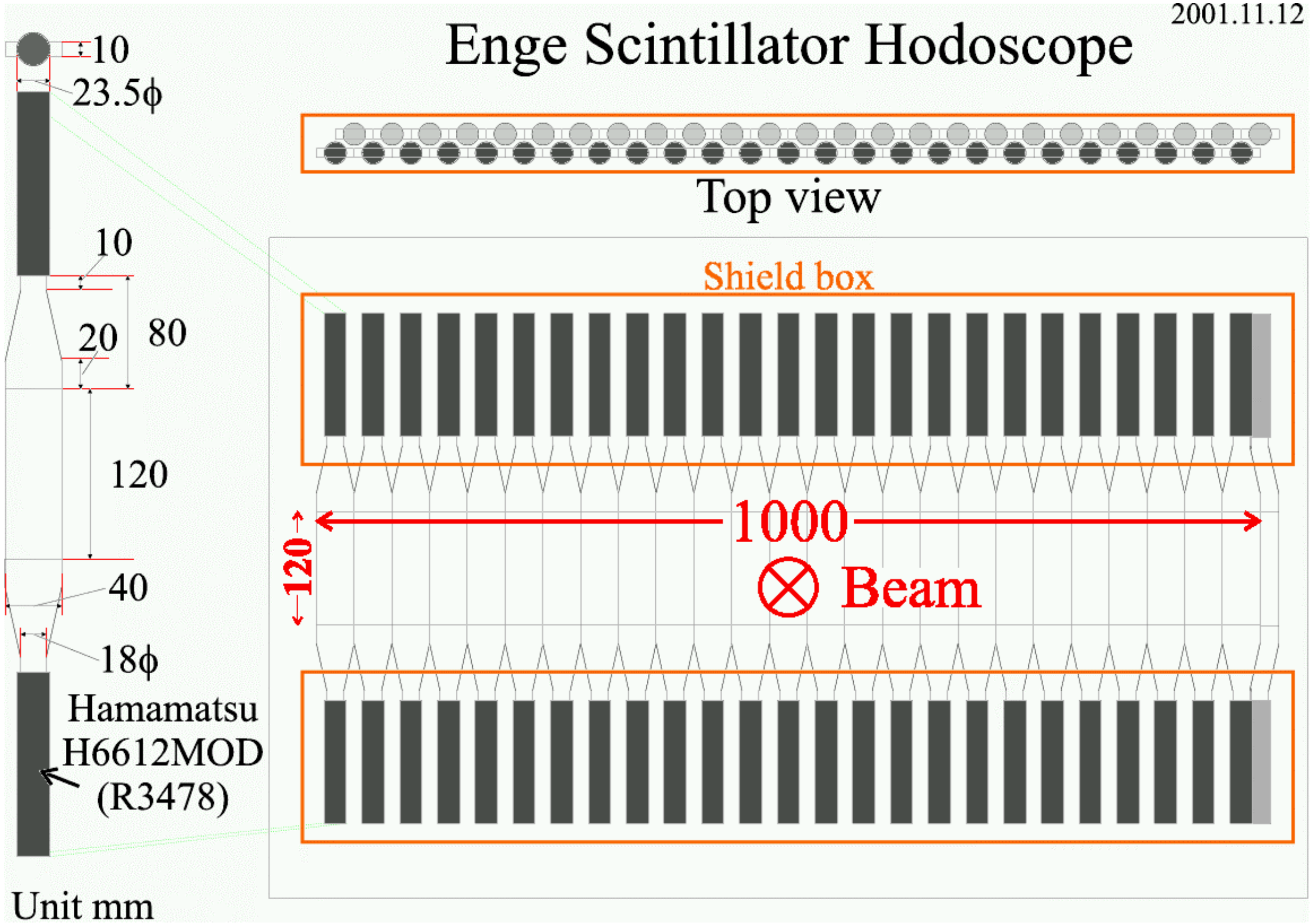
HKS hodoscope HTF1X



HKS hodoscope HTF1Y

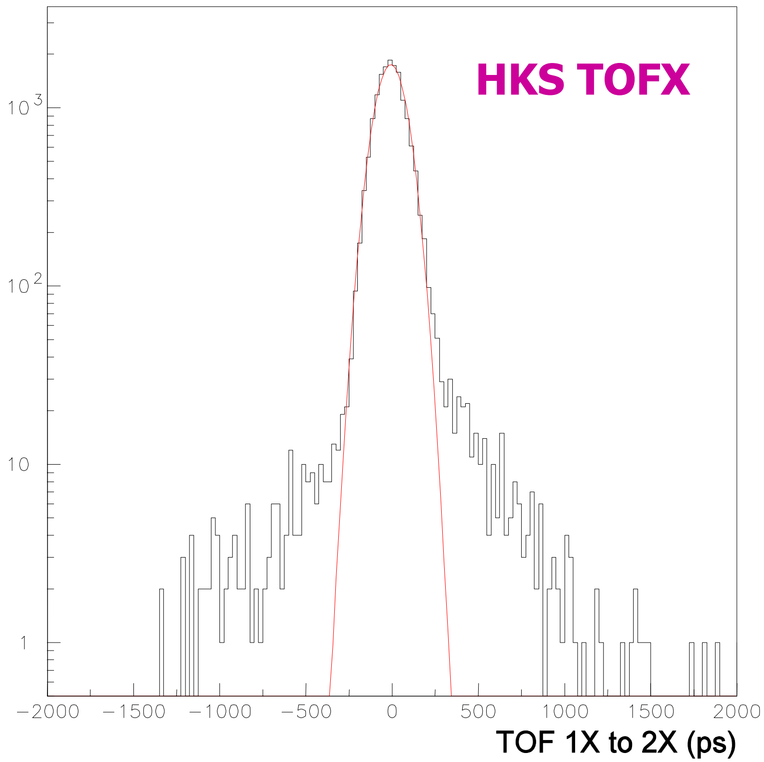


Enge Hodoscope

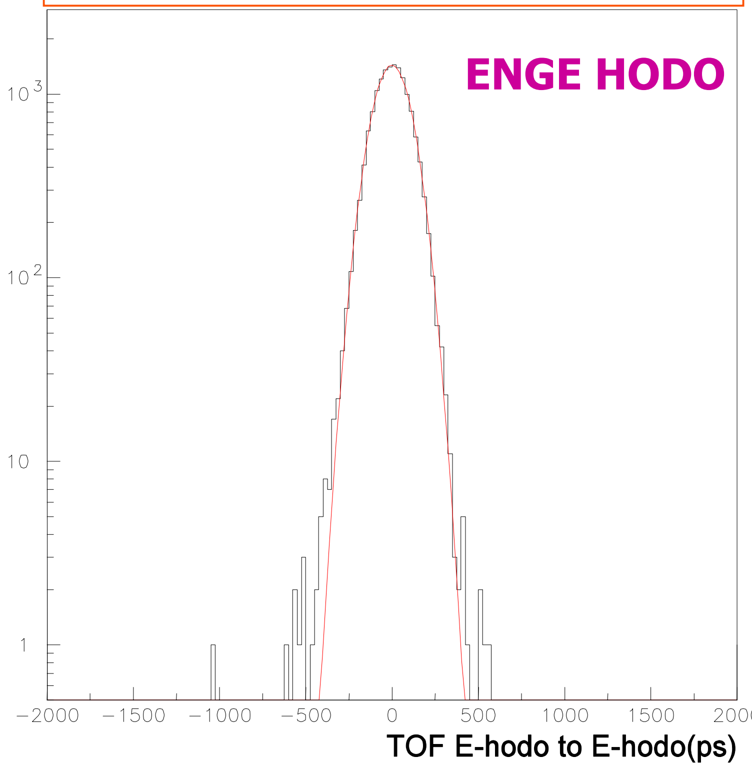


HKS TOF & ENGE HODO test @KEK

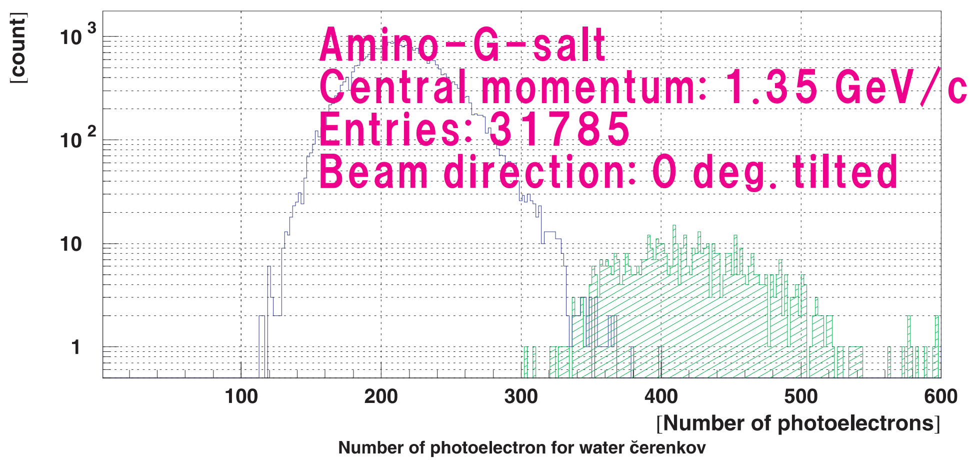
TOF resolution 77ps (rms)

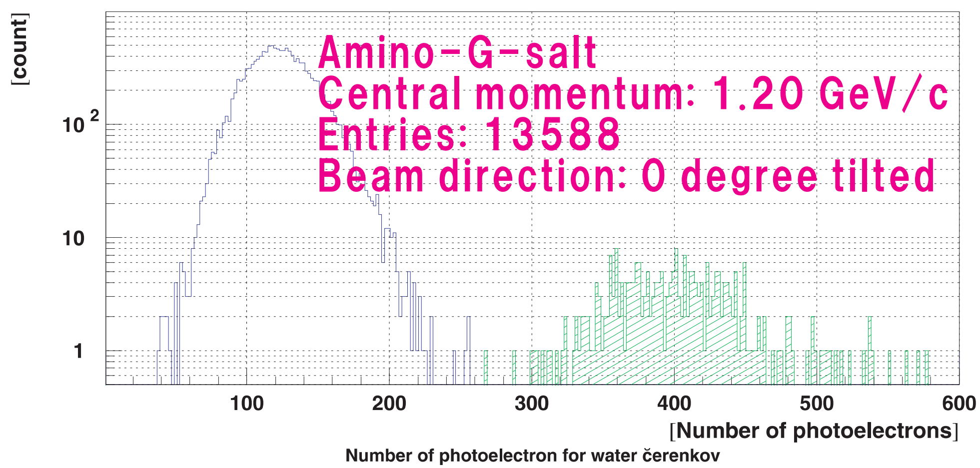


TOF resolution 105ps (rms)

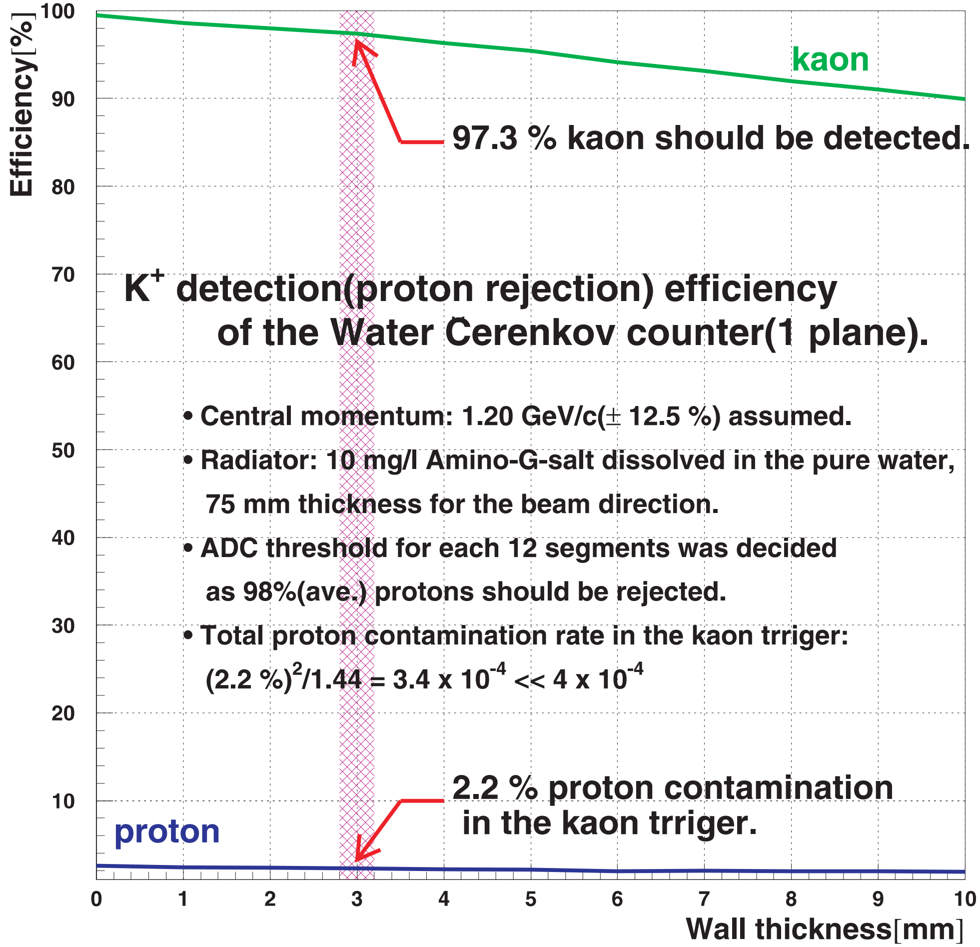


Water Cherenkov counter



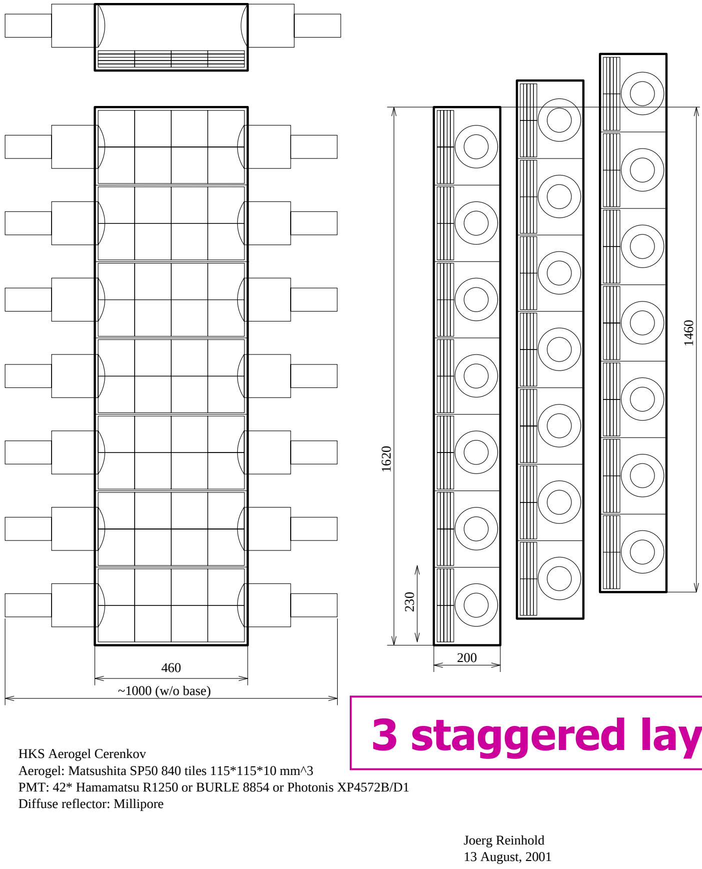


Water Cherenkov counter 2



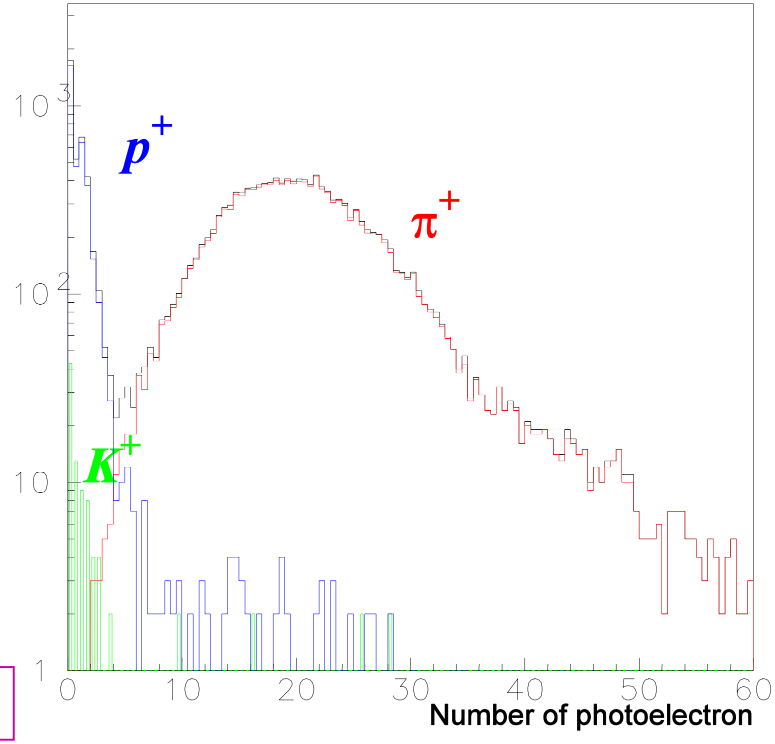
Aerogel Cherenkov Counter

FIU



3 staggered layers

p=1.2GeV/c

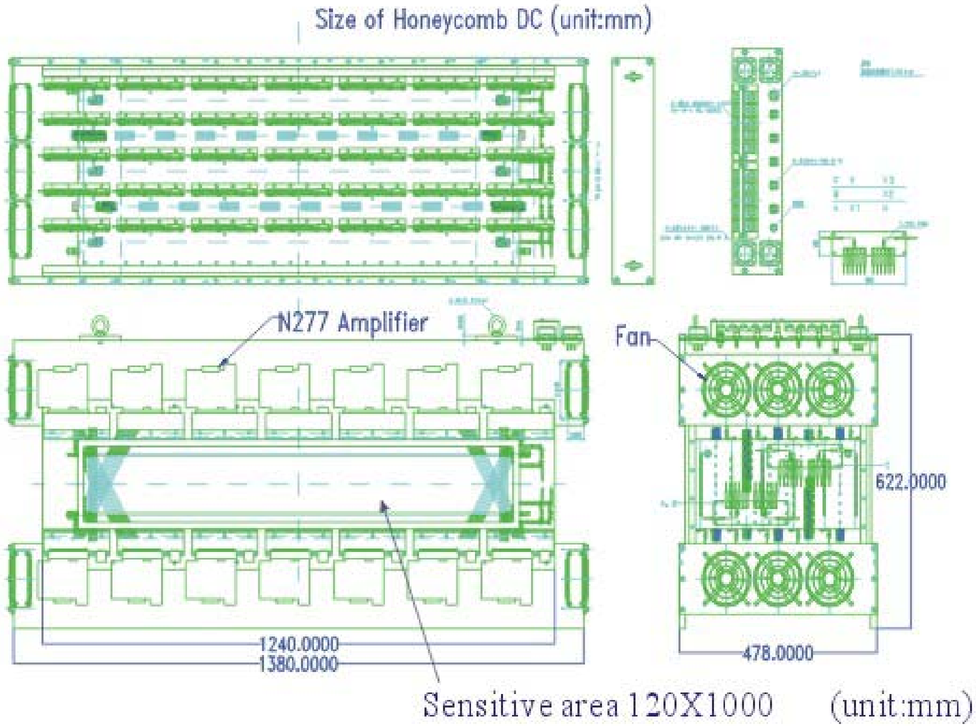


Honeycomb Drift Chamber 1

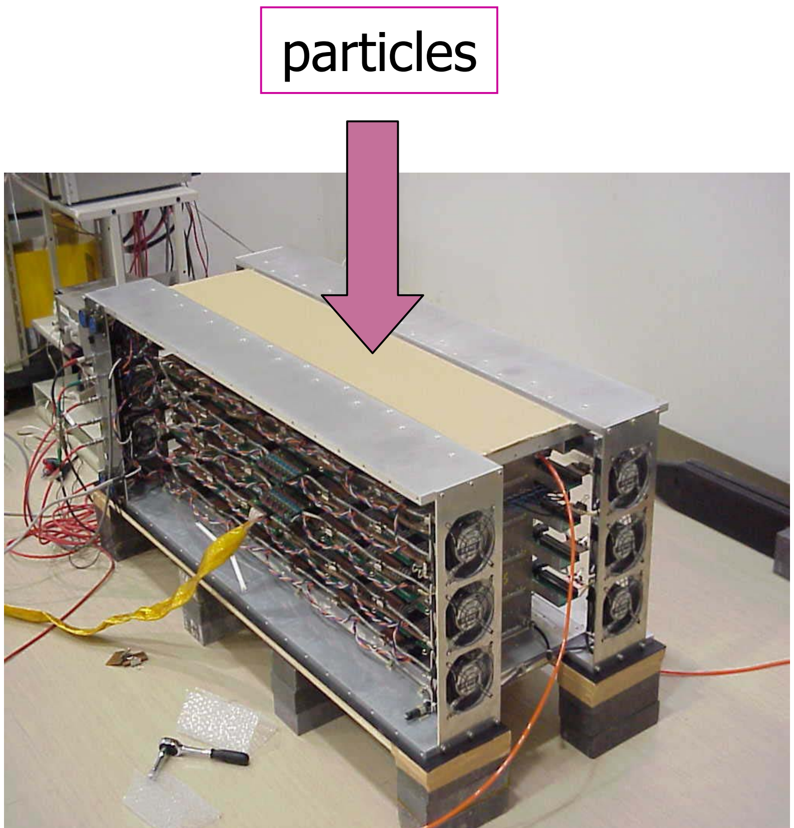
Required performance for the focal plane detector

position resolution (total)	**σ = 150 μm**
incident angle resolution	**a few mrad**

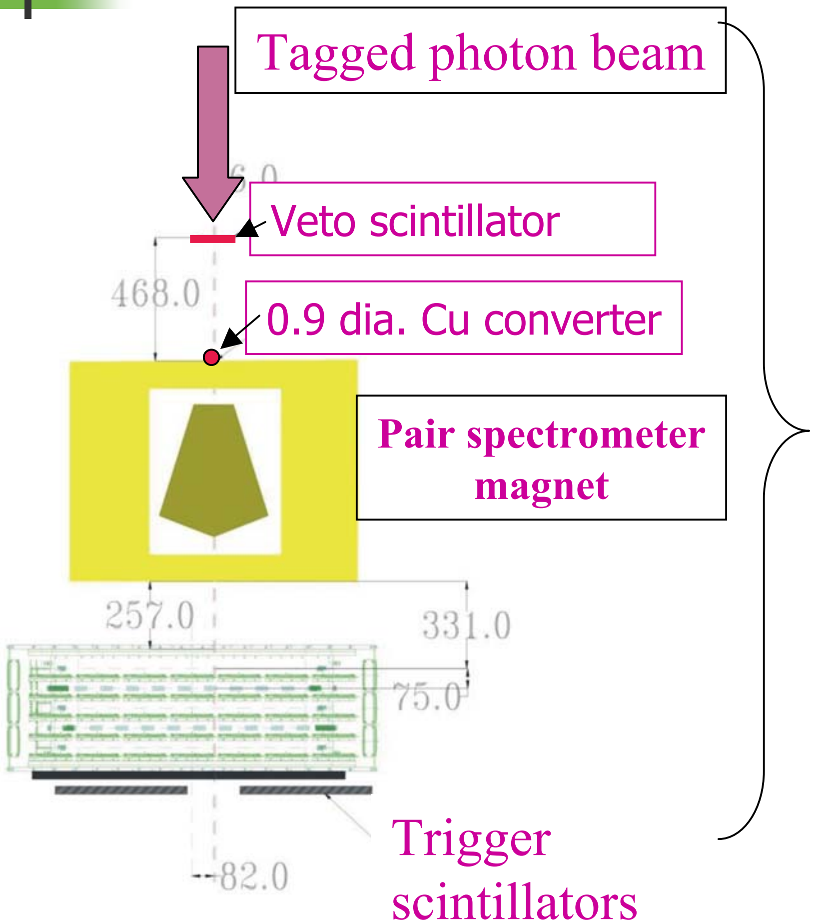
- # of layers
  10(xx' uu' xx' vv' xx')
- Sense wire
  Au plated W (30μmϕ)
- Field & Shield wire
  Al(80 μmϕ)

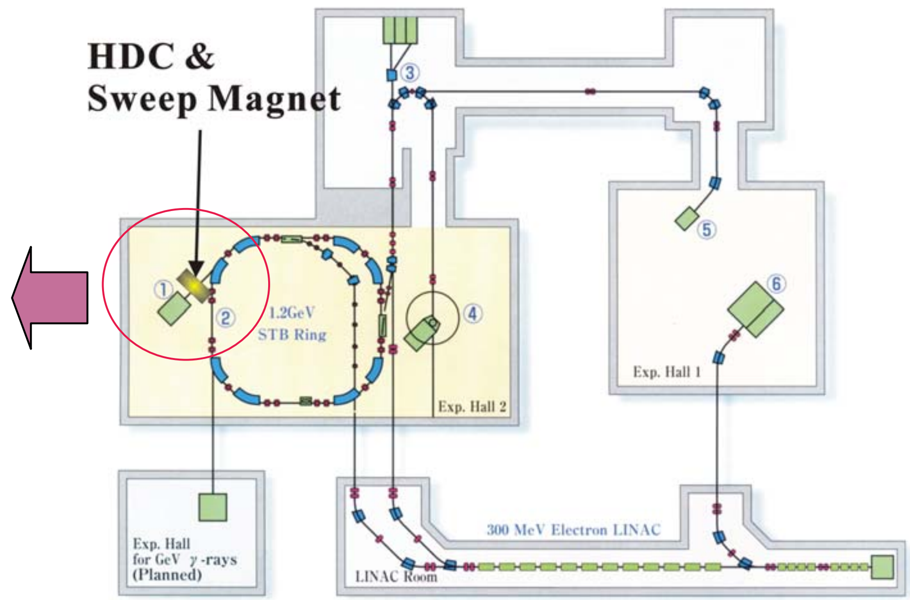


Honeycomb Drift Chamber 2



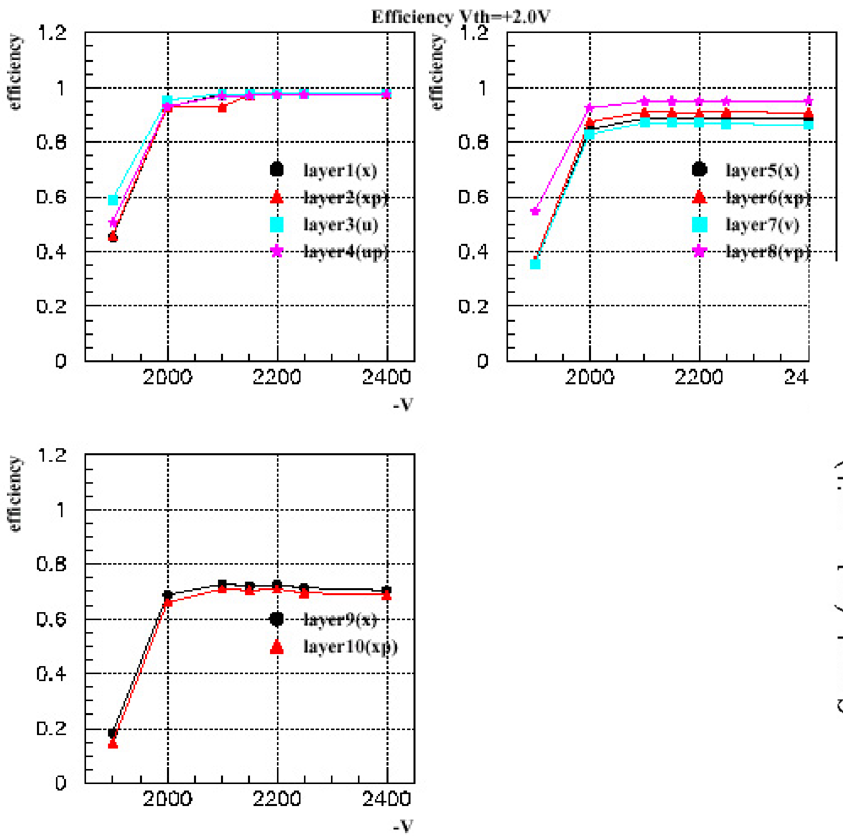
LNS Test Experiment setup





1.2 GeV electron booster ring

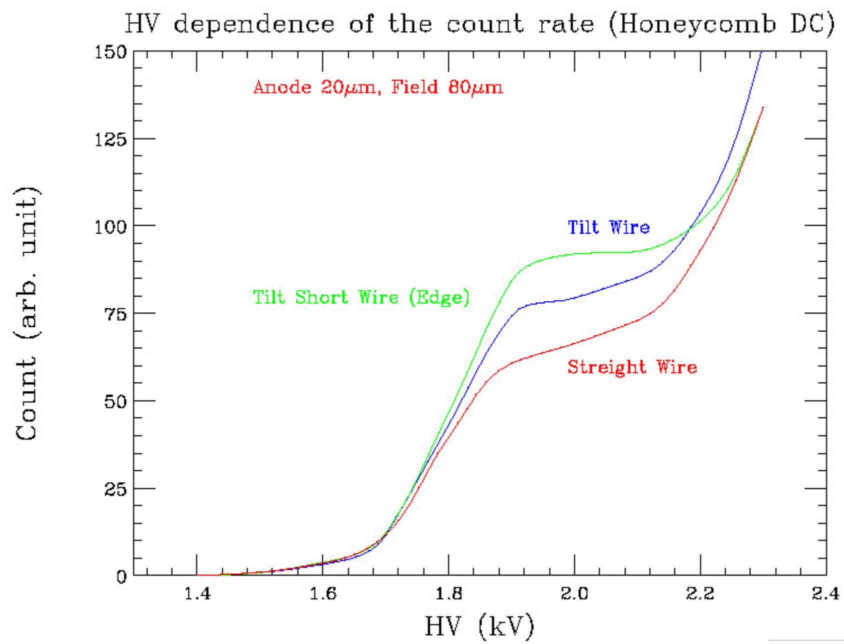
Honeycomb DC performance 1



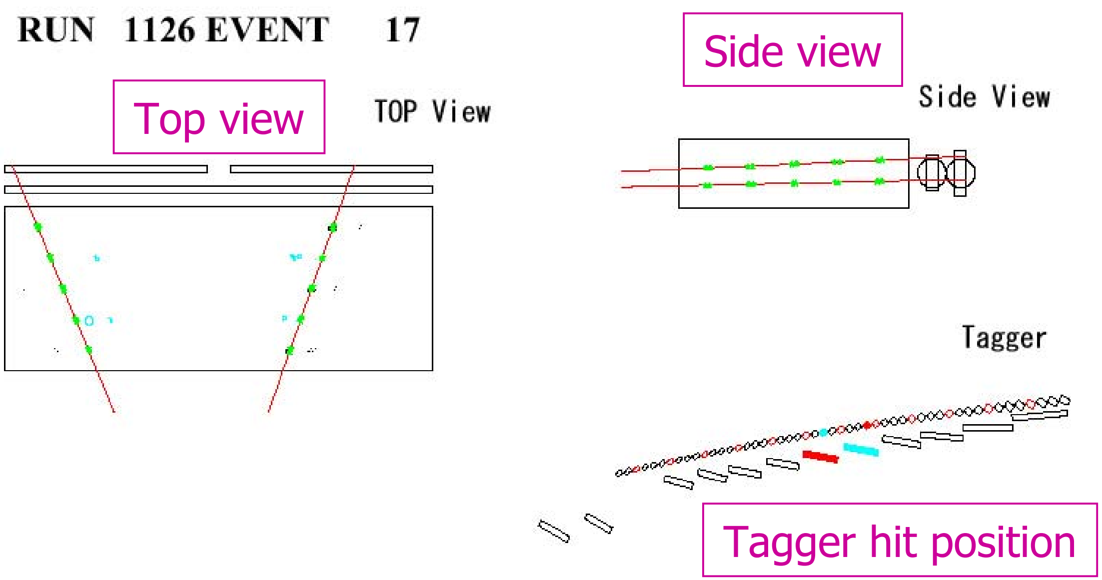
- Good efficiency

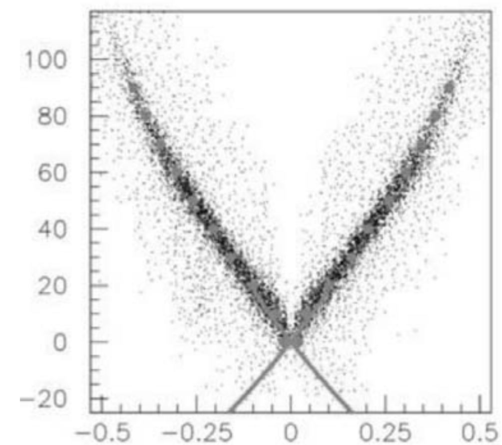
(Plane efficiency is almost 100%)

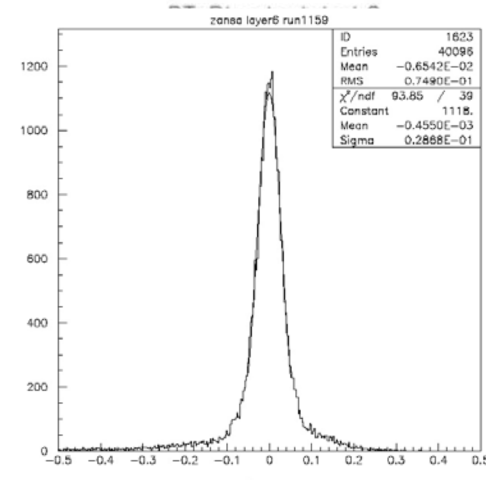
- Ar/Ethane 50/50
- N277L equiv.
- HV = -2.2kV



Honeycomb DC performance 2



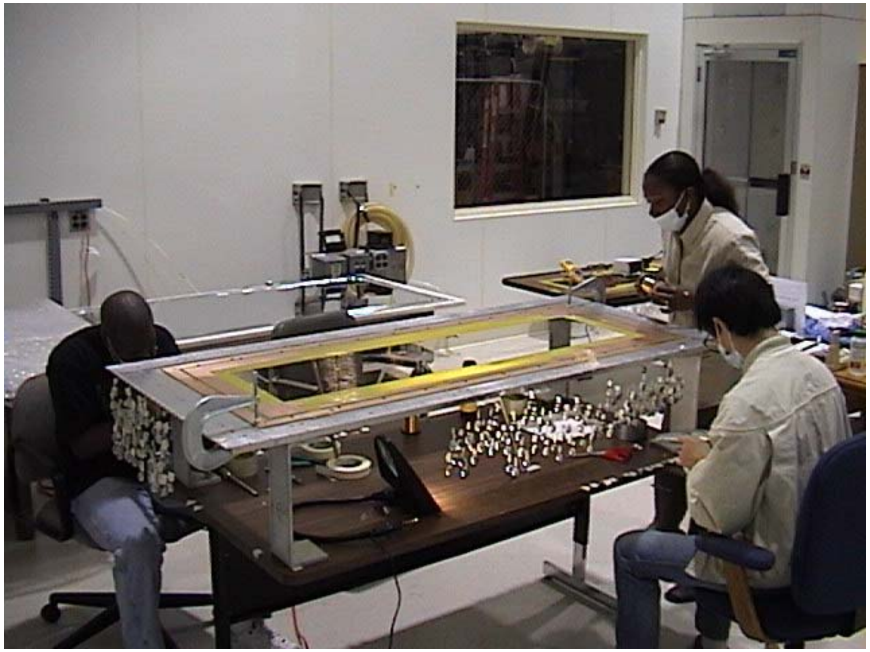


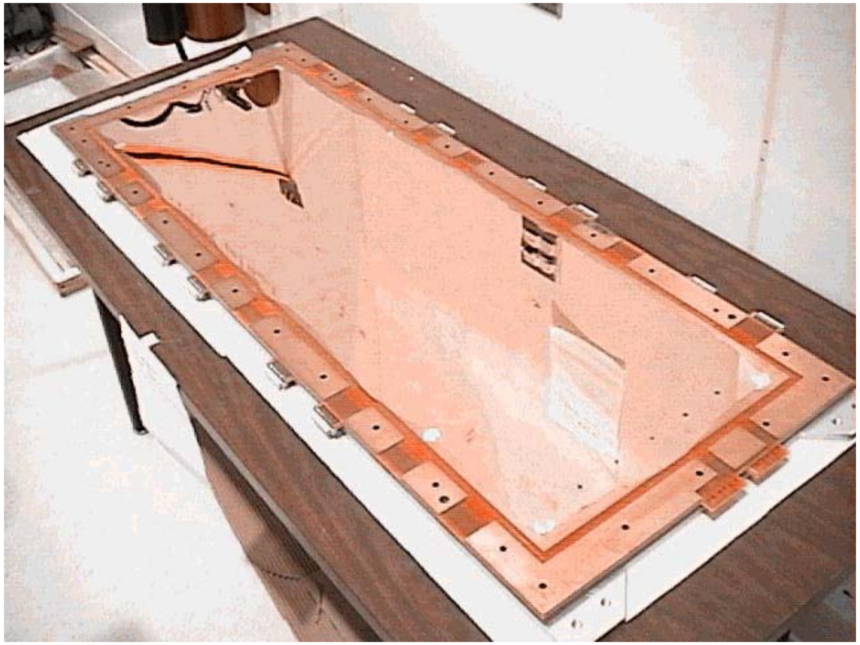


Resolution σ~ 280 μm
(Very preliminary
Will be improved much)

HKS Drift Chamber 1

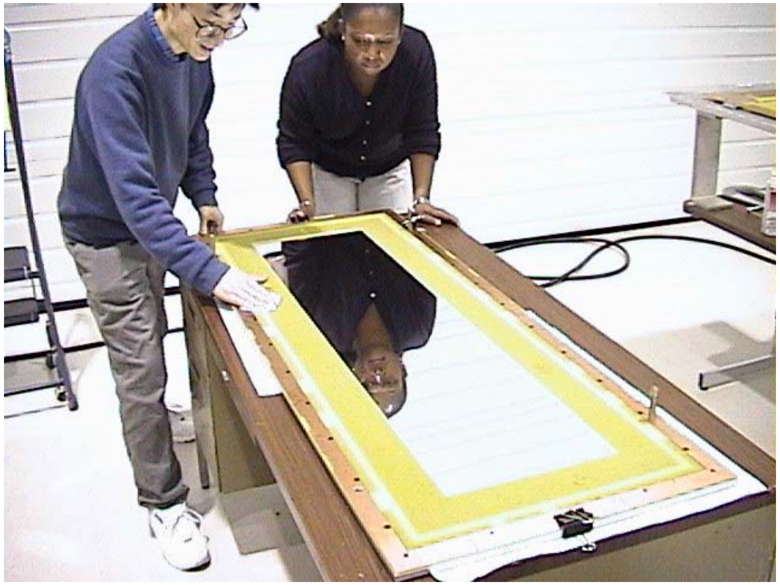
Jlab Clean Room

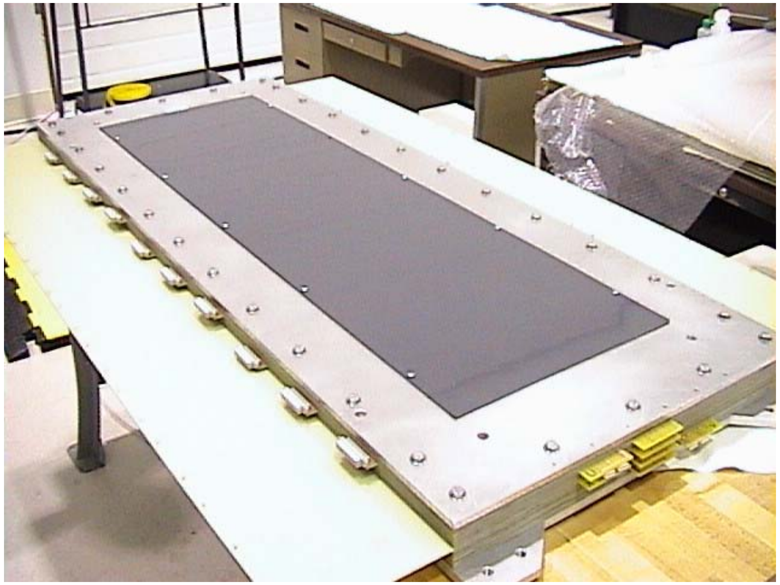




HKS Drift Chamber 2

One of the two HKS drift chamber assembled





HKS Experiment status 1

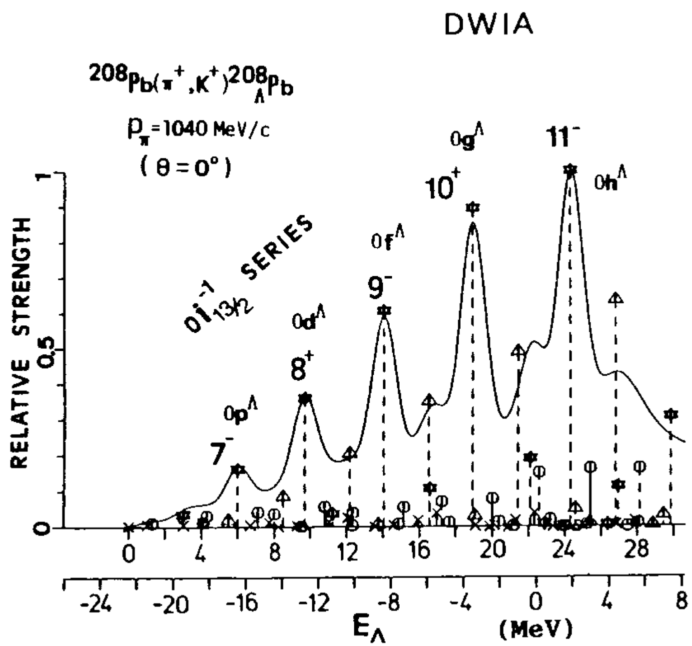
- HKS magnets(Q1, Q2 & D) have been completed together with PS for D.
- Field mapping for Q1 completed, Q2 completed, and for D begins in January.
- Magnets will be shipped in spring when field mapping is completed.
- Magnet will arrive at Jlab in June.
- Engineering design for experimental setup(Beam line, Magnet support, Hall arrangement) under way.

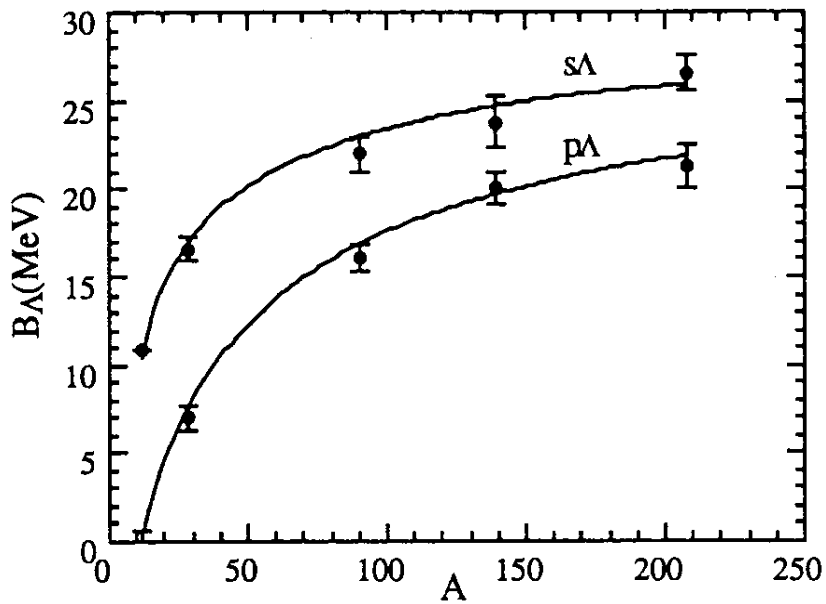
→ Paul Brinza

HKS Experiment status 2

- Detector R&D and construction have been almost done.
- Intensive test of the detectors has been carried out using KEK π,K,p beams and electrons at LNS, Tohoku.
- Detectors will be shipped to Jlab in February.
- Assembly and bench test on site will start in March.
- Magnets and detectors will be ready for experiment anytime after summer.

A Λ Hyperon in nuclear medium





Yield comparison of E01-011 and E89-009

Item	E01-011	E89-009	Gain factor
Virtual photon flux per electron($\times 10^{-4}$)	0.35	4	0.0875
Target thickness(mg/cm^2)	100	22	4.5
Scattered electron momentum acceptance(MeV/c)	150	120	1.2
Kaon survival rate	0.35	0.4	0.88
Solid angle of K arm	18	6	3
Beam current(μA)	30	0.66	45
Estimated yield ($^{12}_{\Lambda}B_{gr}$:counts/h)	51	0.9 (measured)	57

What limited the E89-009 hypernuclear physics experiment ?

- Energy resolution
  - Momentum resolution of the kaon spectrometer limited hypernuclear mass resolution
- Hypernuclear yield rates
  - Kaon spectrometer solid angle limited detection efficiency
  - High count rates at the focal plane of the Enge spectrometer set the limit of maximum beam intensity
  - High accidental background rate

(1)A high-resolution large-solid-angle kaon spectrometer designed

(2) "Tilt method" proposed

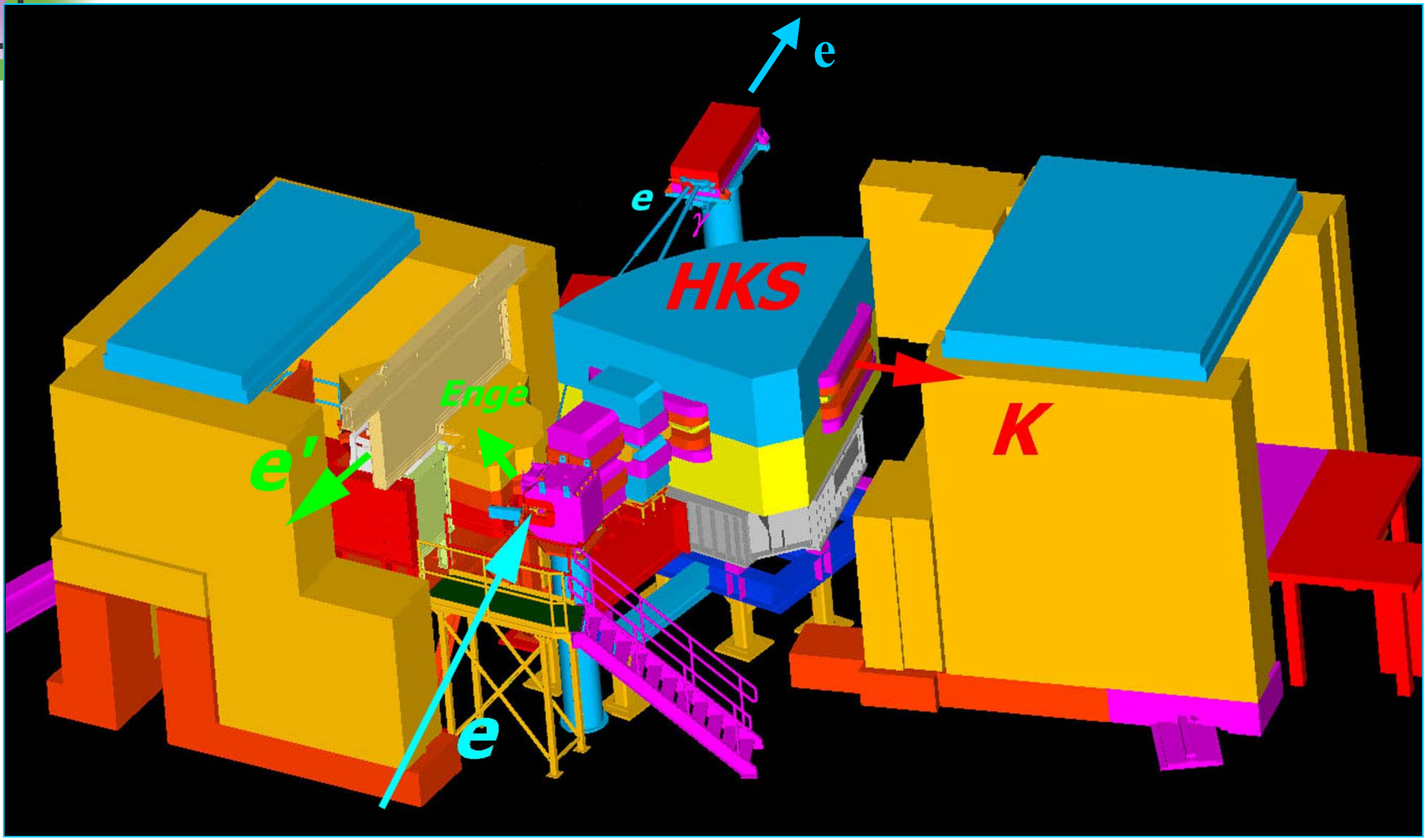
Expected accidental coincidence rate

For the beam current of 30 μA,

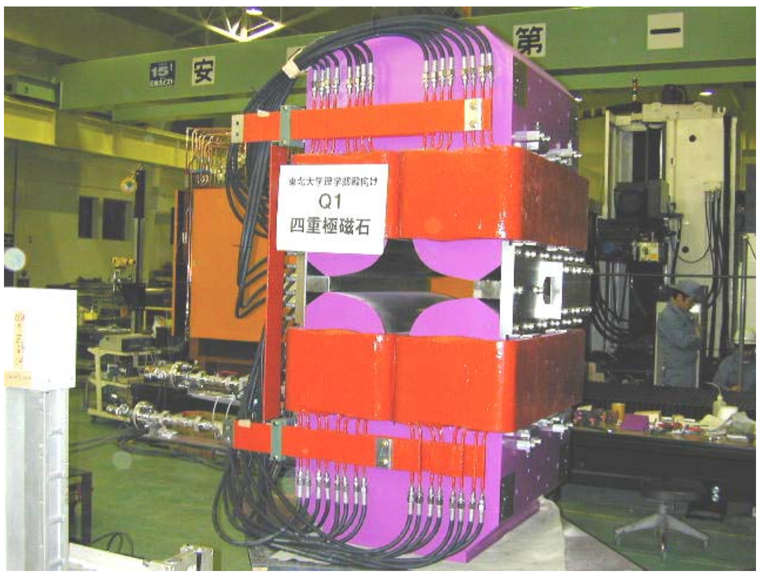
- Electron arm singles rate 2.6 MHz
- Kaon singles rate 340 Hz
- Coincidence time window 2 nsec
  (Offline analysis)

⇨ $N_{acc} = 1.8\ \mathrm{/sec}$

3D CAD View of the experimental setup

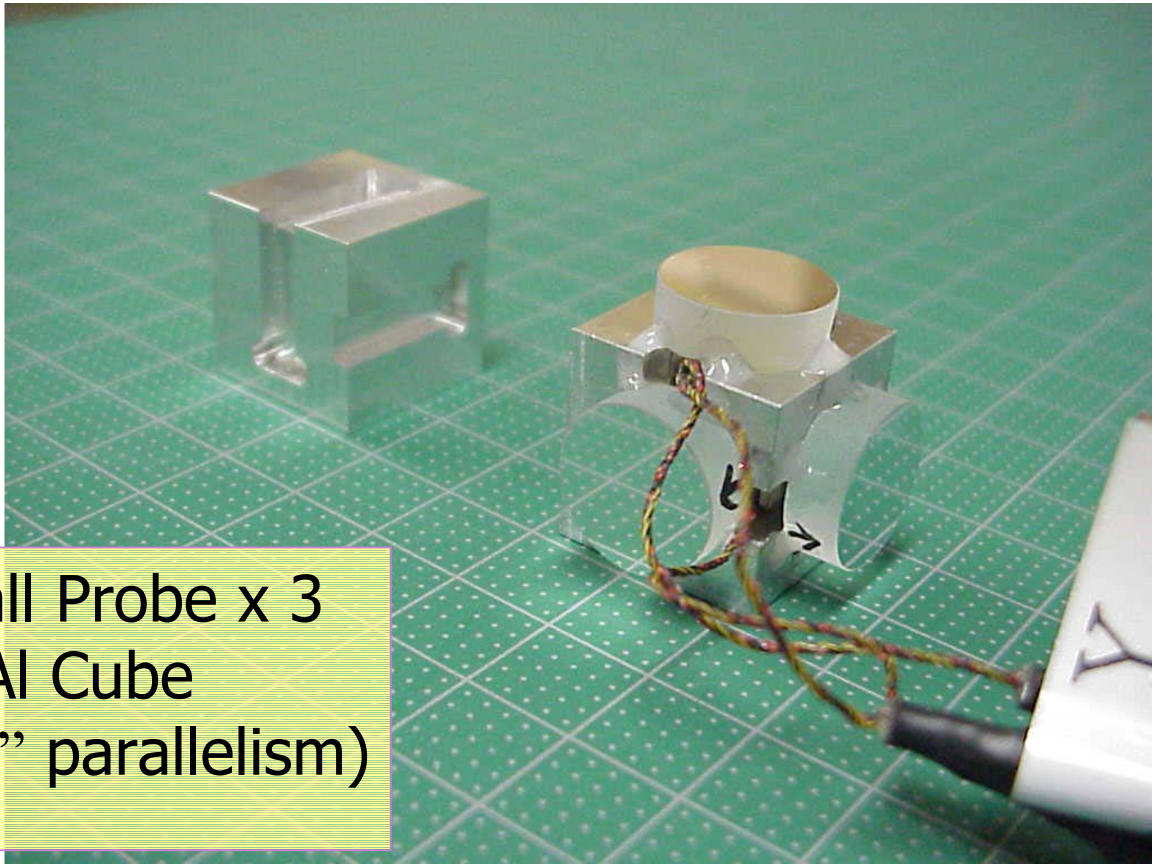


Quadrupole Magnets (Q1, Q2)



Q1, Q2 have been already completed.
Field map is now proceeding.

3 component Hall Probe



- GMW Group3 Hall Probe x 3
- 20x20x20 mm^3 Al Cube
- Three mirrors (5” parallelism)

Goal of the E01-011 experiment

- $^{12}C(e,eK^+)^{12}{}_{\Lambda}B$
  - demonstrate the mass resolution & hypernuclear yield.
  - core excited states and splitting of the p_{Λ}-state of $^{12}{}_{\Lambda}B$….
- $^{28}Si(e,e'K^+)^{28}{}_{\Lambda}Al$
  - Prove the (e,e'K$^+$) spectroscopy is possible for the medium-heavy target possible.
  - precision $^{28}{}_{\Lambda}Al$ hypernuclear structure and ls splitting of p-state….

Expected performance

- Resolution
  - 300 – 400 keV(FWHM) depending on target mass
- Yield
  - About a factor of 50 gain over E89-009
  - Comparable to the present (π^+,K^+) spectroscopy
- Accidental background
  - $8\mathrm{x}10^{-4}$/sec vs. $1.3\mathrm{x}10^{-2}$/(100nb/sr)/sec per 100 keV bin (an order of magnitude better than E89-009)
  - further improvement with the lower beam intensity

E01-011 design principle

- Optimize the experimental kinematics : Similar to E89-009

  ⇒ Matching the momentum acceptances etc.

- Avoid 0 degree Brems associated electrons in ENGE

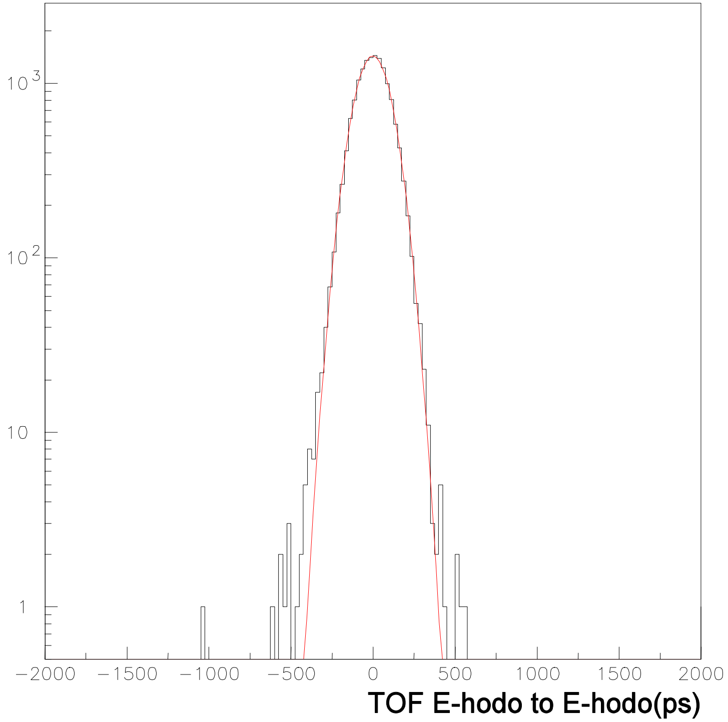
  ⇒ **Tilt method**

- Avoid 0 degree positrons in the kaon arm
- Maximize acceptance of the kaon spectrometer
- Better energy resolution(down to a few 100 keV)

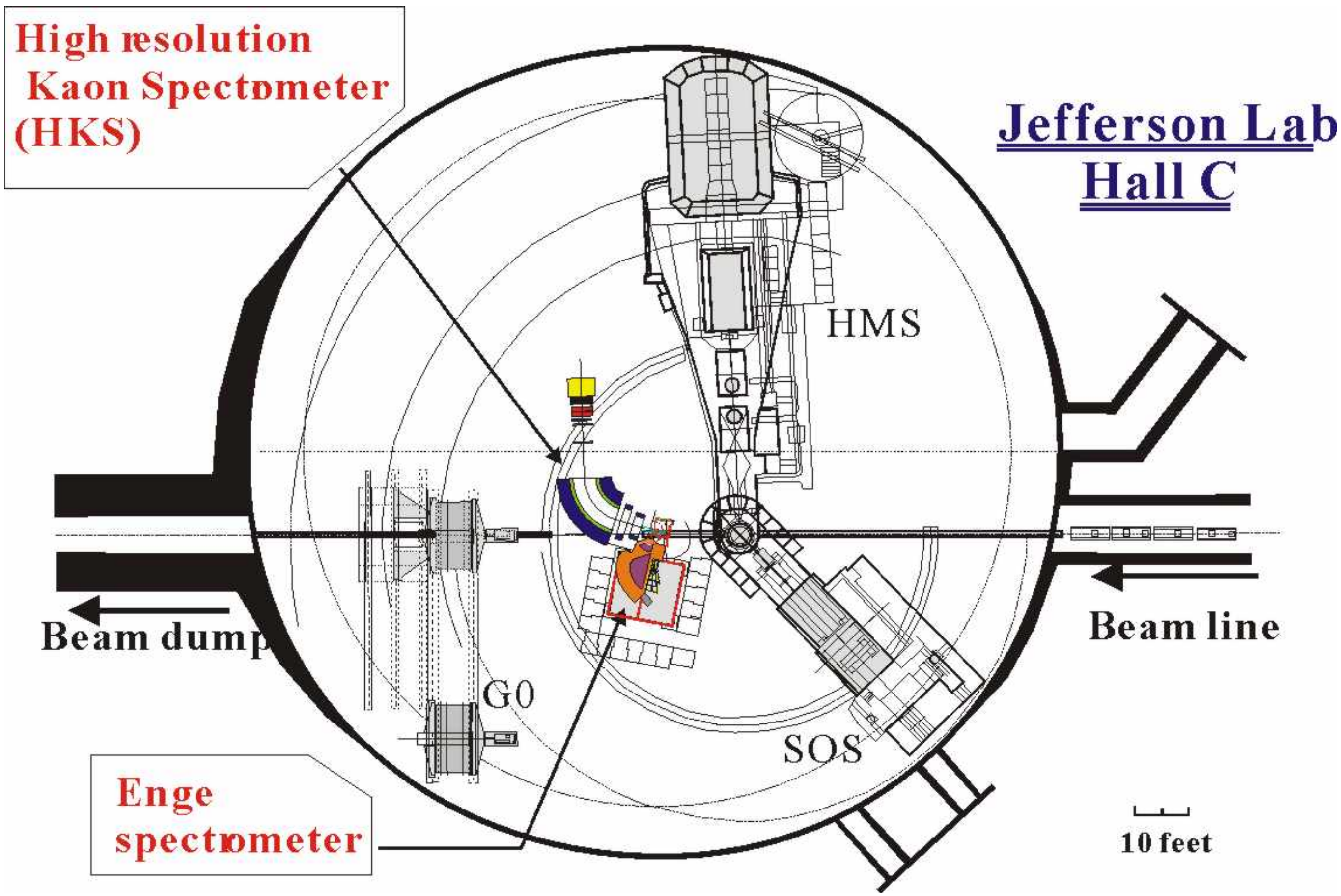
  ⇒ **High resolution kaon spectrometer (HKS)**

Enge Hodoscope test @KEK

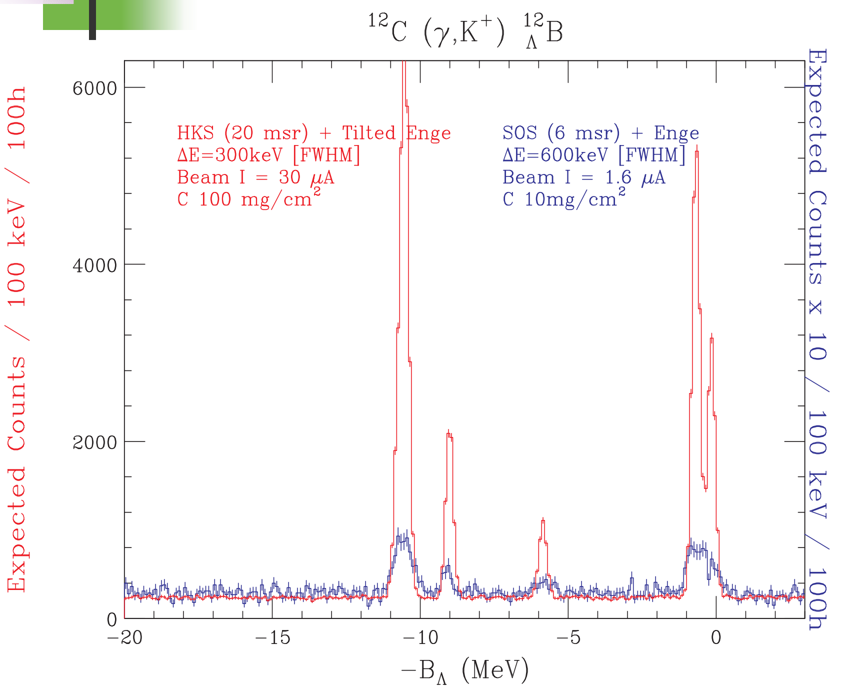
TOF resolution
105ps (rms) achieved

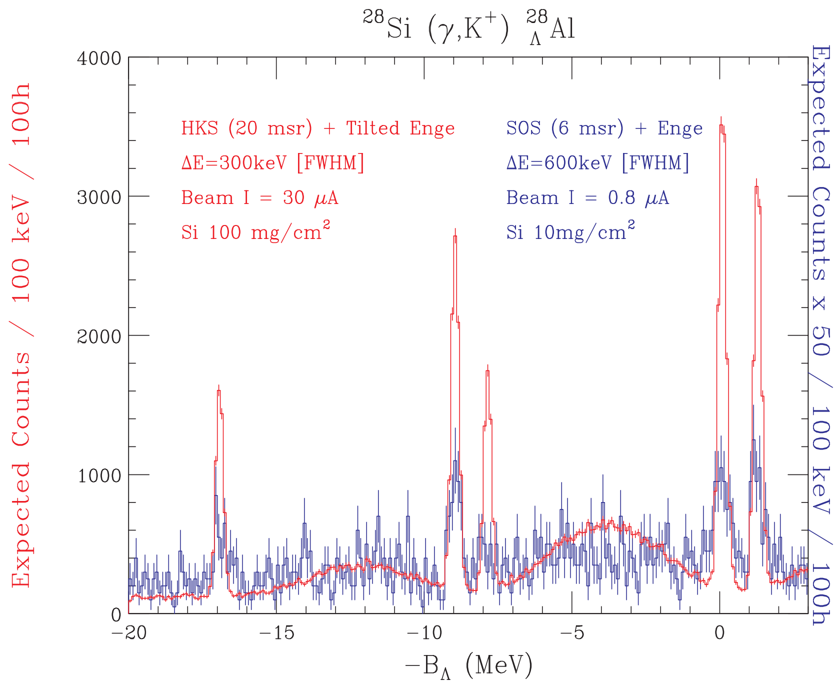


Installation plan of the new spectrometer system in Hall C



Expected spectra





Detectors for the E01-011 experiments 1

HKS

	Nomenclature	Dimension	Comments
Drift chamber	HDC1	30^{H}x120^{W}x2^{T} cm	xx'uu'(+30 deg)vv'(-30 deg), 5cm drift
	HDC2	30^{H}x120^{W}x2^{T} cm	xx'uu'(+30 deg)vv'(-30 deg), 5cm drift
Time-of-flight hodoscope	HTF1X	30^{H}x125^{W}x2^{T} cm	7.5^{W} cm x 17 segments, H1949
	HTF1Y	30^{H}x125^{W}x2^{T} cm	3.5^{W}cm x 9 segments, H1949
	HTF2X	35^{H}x170^{W}x2^{T} cm	9.5^{W} cm x 18 segments, H1949
Cerenkov counter	HAC1	46^{H}x162^{W}x2^{T} cm	n=1.05 hydrophobic aerogel, 5" PMT
	HAC2	46^{H}x162^{W}x2^{T} cm	n=1.05 hydrophobic aerogel, 5" PMT
	HAC3	46^{H}x162^{W}x2^{T} cm	n=1.05 hydrophobic aerogel, 5" PMT
	HWC1	35^{H}x180^{W}x3^{T} cm	10^{W} cm x 18 segments, H1161
	HWC2	35^{H}x180^{W}x3^{T} cm	10^{W} cm x 18 segments, H1161

Detectors for the E01-011 experiments 2

ENGE

Drift chamber	EDC	$12^{H}x100^{W}x30^{T}$ cm	xx'uu'xx'vv'xx'(uu',vv' +-30 deg)
Time-of-flight hodoscope	EHOD1	$12^{H}x100^{W}x1^{T}$ cm	4^{W} cm x 25 segments, H6612
	EHOD2	$12^{H}x100^{W}x1^{T}$ cm	4^{W} cm x 25 segments, H6612
	EHOD3	$5^{H}x100^{W}x2^{T}$ cm	100^{W} cm x 1 segments, H6612

Correlation of kaon and electron momenta, and hypernuclear mass